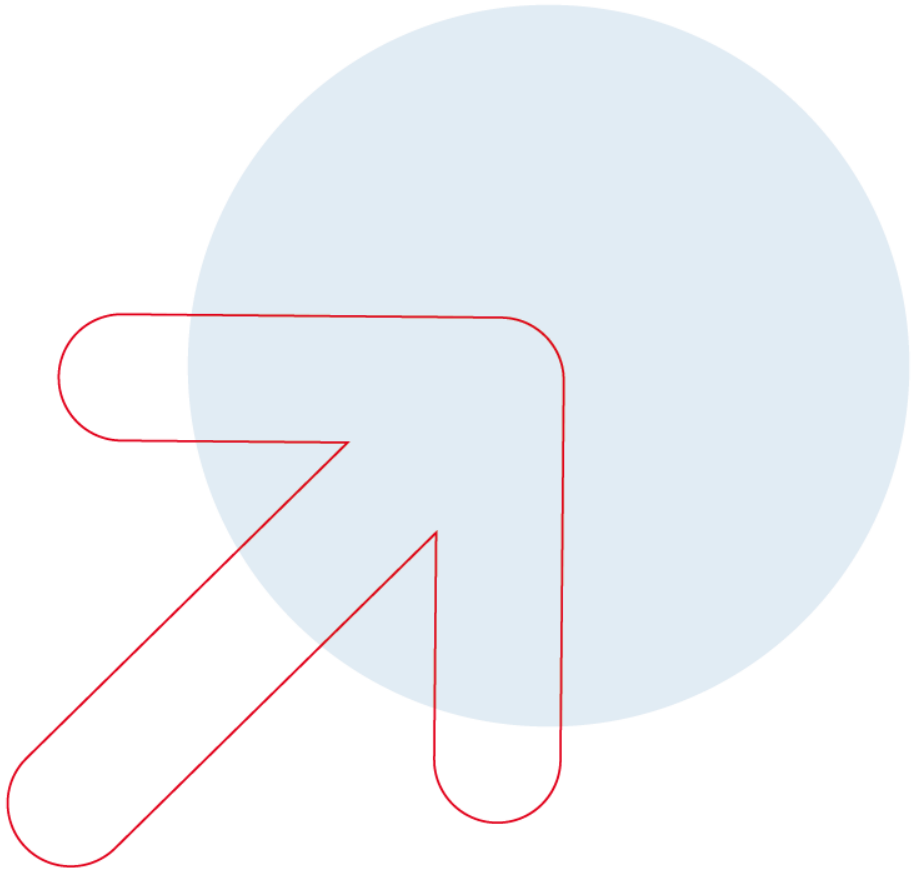
BoR (23) 41

WIK-Consult • Final Report

Study for BEREC



Study on wholesale mobile connectivity, trends and issues for emerging mobile technologies and deployments

FINAL REPORT

Authors: Ilsa Godlovitch, Sonia Strube Martins, Christin Gries, Julian Knips, Christian Wernick

Bad Honnef, 27 March 2023

WIK CONSULT

Imprint

WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany
Phone: +49 2224 9225-0
Fax: +49 2224 9225-63
eMail: info@wik-consult.com
www.wik-consult.com

Person authorised to sign on behalf of the organisation

General Manager	Dr Cara Schwarz-Schilling
Director	Alex Kalevi Dieke
Director Head of Department Networks and Costs	Dr Thomas Plückebaum
Director Head of Department Regulation and Competition	Dr Bernd Sörries
Head of Administration	Karl-Hubert Strüver
Chairperson of the Supervisory Board	Dr Thomas Solbach
Registered at	Amtsgericht Siegburg, HRB 7043
Tax No.	222/5751/0926
VAT-ID	DE 329 763 261

Contents

Table of figures

1 Executive summary

1.1 Background to the study

Mobile communications is currently in a state of transition, as 4G networks are upgraded to 5G and physical SIM cards are replaced with eSIM. Further technological and service developments will follow with the deployment of 5G Standalone networks which support quality-assured services.

This study examines technical developments in mobile connectivity, implications for the value chain and the possible roles that could be played by various stakeholders including mobile network operators, mobile virtual network operators (MVNOs), equipment manufacturers (OEMs), operating system (OS) providers and "verticals" i.e. industrial users of mobile connectivity. It looks at the consequences for sustainable competition and consumer welfare, and discusses the possible roles that NRAs could play in supporting competition, innovation and digital inclusion in the context of these technological developments in mobile communications.

1.2 What is 5G and how is it progressing?

5G has the potential to enhance bandwidths, transfer data with next to no latency and ultra-high reliability as well as supporting a massive expansion of devices in a network cell. However, these benefits, particularly those beyond enhanced bandwidths, can only be achieved when 5G networks are deployed with the associated core network (5G Standalone (5G SA) – also referred to as "full 5G") and not only on top of the 4G core (5G Non-Standalone (5G NSA) – "basic 5G"). The use of frequencies in the midband (3.6Ghz) and millimetre wave (26GHz) and the densification of the network through the use of small cells will also be needed to boost capacity in areas of high demand.

Spectrum in the 5G pioneer bands (in particular 700MHz and 3.6GHz, but less so 26GHz) has been awarded in most EEA countries and 5G coverage is increasing rapidly, reaching 66% at the end of 2021. However, nearly all existing coverage is based on lower frequency bands with 5G NSA which will provide basic levels of 5G. "Full" 5G rollout is expected to begin in 2023 and could take 5 to 8 years to be completed. Estimates suggest that commercial deployment of the 3.6 GHz band will reach up to 60% population coverage, while the remaining territory will mainly be covered by sub-GHz frequencies.

While deployment of public 5G SA networks may take time, more progress has been made in deploying private 5G networks ("campus networks"), which are expected to play a significant role in delivering high quality and reliable coverage for enterprises in

localised areas. QoS-optimised services based on network slicing over the public 5G network are expected to be key for the delivery of tailored solutions for SMEs and companies which require widespread network coverage, but will not be available until public 5G SA deployments are further progressed.[1]

1.3 What is eSIM and how is it progressing?

eSIM is installed as a component during the manufacturing process rather than being inserted through a separate card. eSIM is considerably smaller than SIM cards today and should enable the installation of mobile connectivity in a wide range of "secondary" devices and for IoT. Because it allows remote provisioning and switching, eSIM should facilitate the deployment of connected devices in the field as well as supporting switching for personal devices. eSIM will also enable consumers to subscribe to multiple services (profiles) on their device.

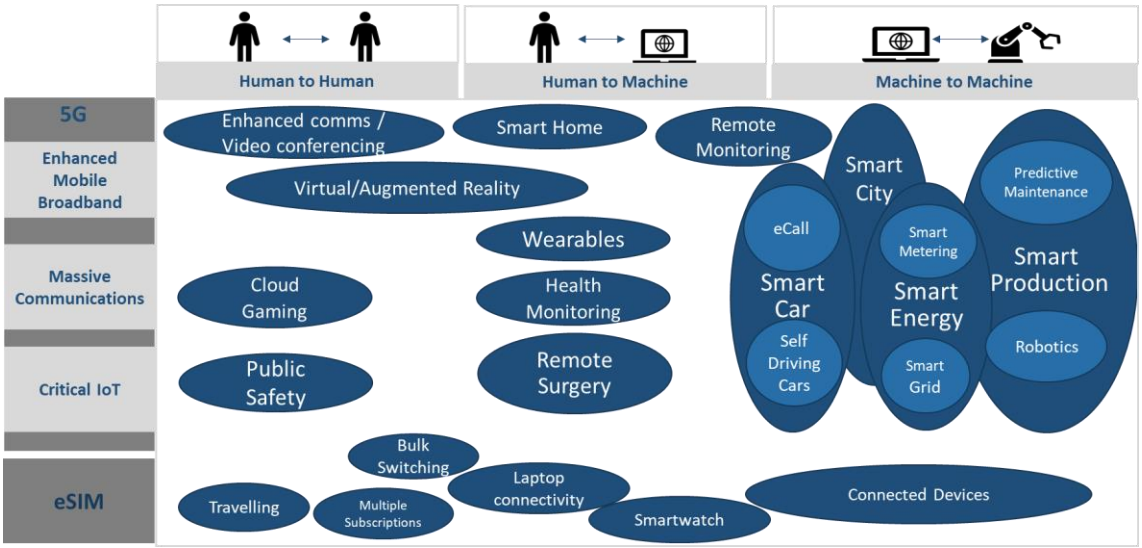
eSIM is present in many of the newer mobile handsets (alongside a SIM card slot) but is not strongly promoted by mobile service providers. Activation of eSIM on handsets is likely to increase with the deployment of smartphones which only accommodate eSIM (already present in the US). Estimates suggest that around one third of smartphones will be connected via eSIM by 2025. Take-up in industrial devices has been slower, except in cars, where the installation has been driven in large part by EU requirements to install eCall capability in new cars which came into force in March 2018.

1.4 Impact on the value chain and the implications for competition and consumer welfare

5G and eSIM could support a wide range of use cases, ranging from industrial machine-to-machine (M2M) applications through to services such as remote monitoring and healthcare. It will also enable customers to experience applications such as AR, VR, and HD video conferencing reliably over a mobile connection, while eSIM will enable consumers to add connectivity subscriptions for services such as travel. An overview of the service opportunities is shown in the following figure.

1 The one example cited was use of this technology in Austria to support minimum quality standards for fixed wireless access.

Figure 1-1: Service opportunities from 5G and eSIM



Source: WIK-Consult

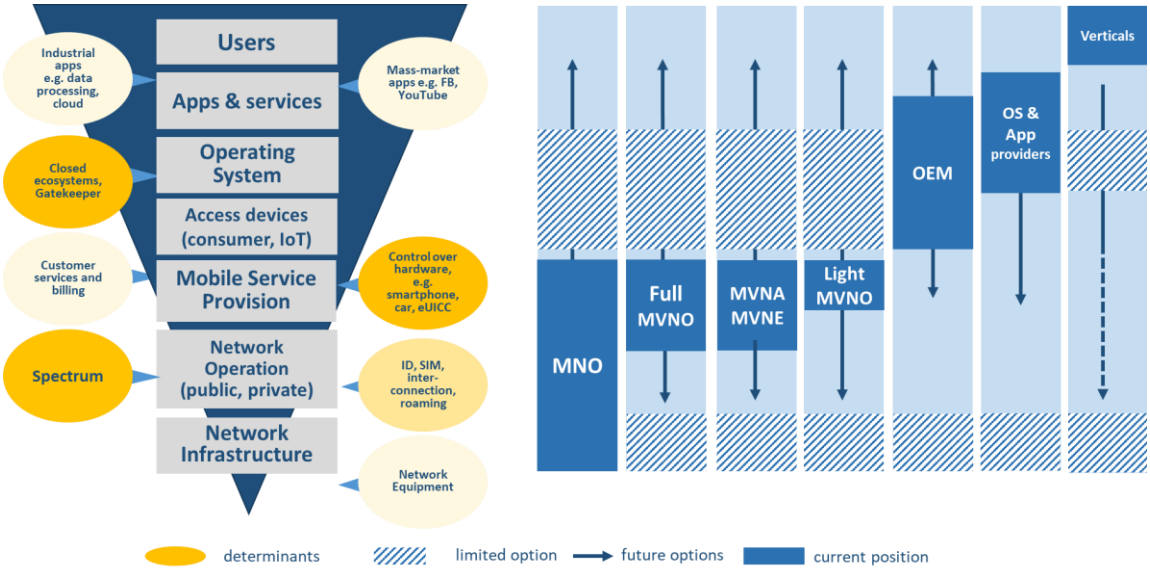
As the range of applications expands, the value chain for mobile communications will evolve. Equipment manufacturers, operating system and app providers and “verticals” themselves are likely to play a greater role, alongside specialist MVNOs which target use cases such as Global IoT or travel.

Technological developments will provide opportunities for players across the value chain to expand into neighbouring areas and/or collaborate with others to provide services. However, it could also be associated with restrictions on competition at the network level, due to increased investment needs for 5G, and at the service level due to lags in renegotiating and updating wholesale access (MVNO and/or roaming) and interconnection contracts to reflect requirements linked to the new technologies.

In addition, new challenges and bottlenecks could emerge from the control that can be exercised by OEM/OS providers over the eSIM and access to functionalities or support needed to provide services such as 5G or support for secondary devices such as smartwatches. This could be particularly problematic if exercised by platforms with “gatekeeper” power. Consumer MVNOs and smaller MNOs without countervailing buyer power could be at most risk from such practices, although specialist IoT MVNOs could benefit if they enter into agreements with OEMs/OS providers.

The following figures provides an overview of the potential opportunities for different players in the evolving mobile value chain as well as factors which may create dependencies or barriers to expansion.

Figure 1-2: The evolving mobile value chain



Source: WIK-Consult

The applications made possible by 5G and eSIM promise to offer significant value to consumers, industrial customers and the economy at large. However, if MNOs alone control the pace of deployment of full 5G capabilities, there is a risk that the benefits to enterprises could be delayed or that services may not meet the specific needs of larger businesses. In addition, the 5G transition could be associated with a reduction in choice, and potentially higher prices for consumers in countries where MVNOs have previously played a significant role in the market, but have not be able to offer competitive services via 5G. Customers which rely on legacy devices for their general communication services or for applications such as alarms will also be impacted by the switch-off of 2G and 3G networks that is likely to follow the deployment of 5G. When fallback to the 2G and 3G variants of voice and SMS services is not possible anymore, potential VoLTE and VoNR compatibility issues may surface that seem to occur in some cases due to different interpretations of standards in implementation. The move towards all-digital processes for sign-up and customer service could also impact certain customer groups.

1.5 Options to address possible competition challenges

Where competition in 5G mobile services is expected to be limited, possible solutions include reserving 5G spectrum for a new entrant or applying obligations relating to MVNO access. Previous experience suggests that new entry can boost attractive offers and innovation, but it might not always be feasible or economically viable. For example,

spectrum has been awarded to new entrants in 5G in BE, DE and PT, but no bidder came forward in AT and CZ. Entry has not always proved to be sustainable.

MVNO obligations can provide an alternative when infrastructure-based competition is not feasible. MVNO obligations have been introduced through single SMP in NO, through merger commitments in AT, DE and IE and in the context of spectrum licence conditions in CZ, FR, EL, NO, PT and DE. Outcomes have been varied and depend on the nature of the obligations applied as well as market context. For example, obligations to *negotiate* access (more common in spectrum licences) or offers which apply to only selected firms (in the context of merger commitments) seem to have been less effective in enabling competition from MVNOs than obligations which establish clear conditions for access that have been open to a range of parties. Delays in obtaining access, high one-time charges for access to 5G, or "pay-per-unit" wholesale charges which are not adapted to the higher volumes consumed via 5G may also have limited the capability of MVNOs to compete in 5G service offers in some cases.

Where NRAs consider that MVNO obligations may be necessary, they will need to be justified based either on (joint) SMP or as a competition measure attached to spectrum licences within the scope of Article 52 EECC. Existing spectrum-based obligations have generally been applied under the previous regulatory framework. Applying MVNO obligations under spectrum licences in accordance with the EECC will in future require a market analysis including assessment of the competitive conditions and impact of any obligations on investment, but (as auction outcomes cannot be pre-determined) could not require an assessment of the market power of specific companies.

As regards the nature of the obligations, in cases where MVNO obligations are needed to support competitive outcomes in the retail market, experience shows that it is important to establish conditions which would enable the MVNO to act independently of its host to the greatest extent possible. This implies the potential to enter as a "full MVNO" from a technological and operational perspective, and conditions which would support VoLTE and give access to new capabilities such as 5G and in future QoS enhanced services at the same or similar timeframe as are available to the host. Moreover, the wholesale pricing regime should enable the MVNO to differentiate its pricing structure from the host including allowing for unlimited data offers. In cases where MVNOs are needed to provide a competitive stimulus, an obligation for MNOs to negotiate MVNO access is unlikely to be sufficient. At the same time, wholesale access obligations including any rules regarding charges should ensure that the host is able to make a reasonable return on its investments, reflecting the risk taken.

In order to limit barriers to deployment and increase choice in the enterprise segment, several Member States have assigned 5G spectrum directly to verticals. This has proved to be successful in a number of cases with a large number of 5G private networks being

deployed in countries such as Germany, France and Finland. However, dedicated spectrum for verticals tends to be relevant to larger businesses with localised connectivity requirements and may not meet the needs of SMEs or businesses which require widescale coverage. Countries such as FR and NO have addressed concerns around service to those groups by including a licence condition that MNOs should meet reasonable requests for quality-assured services or offer spectrum leasing.[2]

eSIM provides opportunities for greater competition in the supply of cross-border IoT, as well as the potential to switch provider for devices in the field, which was previously very complicated. However cross-border (and in particular global) IoT services inevitably rely to some extent on wholesale international roaming. Attention to roaming conditions (including those provided to specialist IoT MVNOs) is therefore important in supporting competition in cross-border IoT. In addition, switching for M2M can present challenges in some situations due to the way in which the standard for eSIM is implemented for M2M.[3] This is another area which could benefit from improvements to standards, monitoring and possible guidance by BEREC.

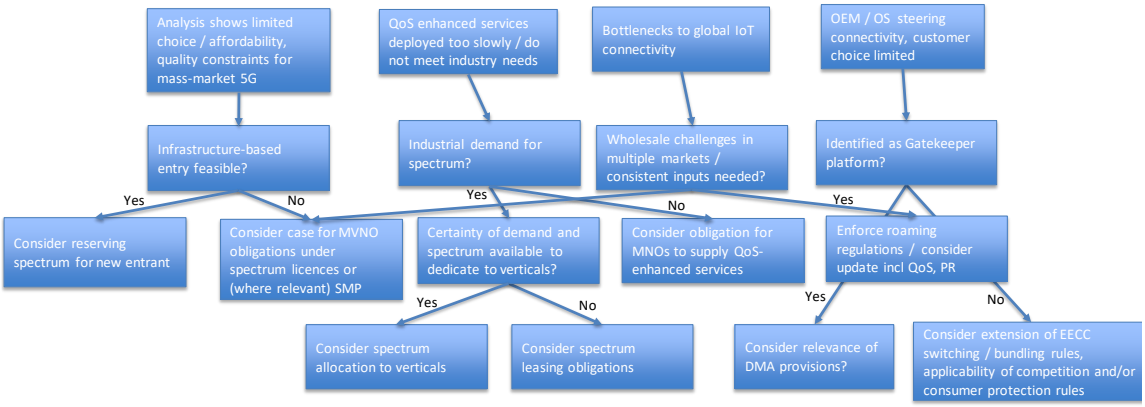
Problems relating to steering of connectivity or restrictions on switching by "gatekeeper" OEM/OS providers could be addressed under newly introduced provisions in the Digital Markets Act. It could also be explored whether the DMA could also address cases where OEM/OS gatekeepers limit access to certain functionality needed to support connectivity. However, the DMA is only applicable to platforms with gatekeeper status in "core platform services", and therefore may not resolve lock-in which is driven by OEMs such as car manufacturers bundling contracts for connectivity with the sale of vehicles. Countries such as DK have sought to address this concern by extending the scope of national measures transposing the EECC including measures concerning switching and bundling to OEMs.

An overview of the options which could address the challenges identified is provided in the following figure.

2 In FR the MNO may choose between these options. In NO, spectrum leasing must be offered if the MNO cannot deliver the services requested.

3 Specifically, if the SM-SR is under the control of the former connectivity provider, its co-operation would be needed to switch to a new provider.

Figure 1-3: Overview of possible solutions that may be relevant in given situations



Source: WIK-Consult

In cases where competition challenges are present, the appropriate solution will depend on the specific case and should follow an analysis of the challenges experienced by end-users, market conditions and the potential effectiveness, costs and benefits of possible solutions in the market or market segments which are affected.

2 Introduction and methodology

2.1 Background and objectives

Mobile communications is currently in a state of transition, as 4G networks are upgraded to 5G and physical SIM cards are replaced with eSIM. Further technological and service developments will follow with the deployment of 5G Standalone networks which support quality-assured services.

These technological developments could provide significant opportunities for a range of players to offer tailored services to businesses and develop IoT applications in the field. eSIM will also open up opportunities for consumers to have multiple subscriptions on their handsets which could increase competition in segments such as “travel” communications or enable them to separate business and personal communications.

The development of industrial applications in sectors such as automotive, healthcare and smart cities is likely to involve a range of players beyond those traditionally involved in telecommunications, and some applications (such as future applications in connected automotive mobility) will also require global connectivity, potentially with quality of service guarantees that cross borders.

Tapping innovation from different players across the value chain, including customers as well as specialist application providers and MVNOs could help to ensure that the diverse needs of different customer groups are met. At the same time, it is necessary to ensure that consumers that have relied on low cost offers and basic handsets are not left behind in the transition to a 5G and eSIM-enabled mobile environment.

This study examines technical developments in mobile connectivity, implications for the value chain and the possible roles that could be played by various stakeholders including mobile network operators, MVNOs, verticals and other stakeholders. It looks at the consequences for sustainable competition and consumer welfare, and discusses the possible roles that NRAs could play in supporting competition, innovation and digital inclusion in the context of these technological developments in mobile communications.

2.2 Methodology

The report draws on evidence from:

- A review of literature and documentation from NRAs and stakeholders regarding mobile technologies, wholesale mobile connectivity solutions and effects on the market

- An analysis of indicators relating to the availability of different options for wholesale connectivity (such as MVNO access, or the availability of dedicated spectrum or spectrum leasing opportunities) and corresponding outputs for end-users in terms of choice, price and quality and the availability of new vertical applications
- 23 structured interviews involving mobile network operators, equipment manufacturers, MVNOs, verticals and NRAs; and
- An online survey conducted between October-November 2022, for which we received a total of 48 responses including 27 responses from NRAs, 8 responses from MNOs, 9 responses from MVNOs and 4 from verticals in three different industrial segments (automotive, industrial / manufacturing and smart cities).

Data was gathered to the extent possible for the EU27 + Norway, including key outcome indicators for consumer markets. Additional focus was placed on gathering insights from 6 countries (AT, DE, CZ, NO, IE, FR) where regulatory intervention has been applied to promote competition and choice for end-users including verticals (including dedicated access or spectrum leasing obligations for verticals and/or MVNO access obligations linked to SMP, spectrum licences or mergers). The aim was to understand the context and reasons underlying the conditions applying and examine take-up and, to the extent possible, any outcomes associated with those measures.

2.3 Structure of the study

- Chapter 3 discusses technological and market developments, with a focus on 5G NSA and SA and eSIM
- Chapter 4 considers the implications of emerging technologies for the value chain
- Chapter 5 examines the impact of 5G and eSIM on competition and consumer welfare
- Chapter 0 describes regulatory options that may be relevant in addressing problems that may arise in connectivity or at the OEM/OS layer.

The data gathering methodology and questionnaires used for the online survey as well as a list of 5G private networks are included in the Annexes.

3 Technological and market developments

In this chapter we describe technological developments in mobile with a focus on 5G and eSIM, and discuss the diffusion of these technologies across Europe. Key findings are:

- The main advantages of 5G are enhanced bandwidths, the possibility to transfer data with next to no latency and ultra-high reliability as well as a massive expansion of possible devices in a network cell. In addition 5G offers significant potential for customization and flexibility through network slicing (when the network is split into different layers).
- These benefits, particularly those beyond enhanced bandwidths, can only be achieved when 5G networks are deployed with the associated core network (5G standalone) and not only on top of the 4G core (5G non-standalone). The use of frequencies in the mid-band (3.6Ghz) and millimetre wave (26GHz) and the densification of the network through the use of small cells will also be needed to boost capacity in areas of high demand.
- Spectrum in the 5G pioneer bands (700MHz and 3.6GHz) has been awarded in most EEA countries and 5G coverage is increasing rapidly reaching 66% at the end of 2021. However, existing coverage will not deliver the full capabilities of 5G as it is nearly all based on lower frequency bands with 5G NSA. “Full” 5G rollout is expected to begin in 2023 and could take 5 or more years to be completed. Estimates suggest that commercial deployment of the 3.6 GHz band will reach up to 60% population coverage, while the remaining territory will mainly be covered by sub-GHz frequencies.
- Private 5G networks (“campus networks”) are expected to play a significant role for enterprises needing high quality and reliable coverage in localised areas. The industrial manufacturing sector and transport hubs are the current frontrunners in deploying these networks. QoS-optimised services based on network slicing are expected to be key for the delivery of tailored solutions for SMEs and companies which require widespread network coverage.
- eSIM is installed as a component during the manufacturing process rather than being inserted through a separate card. eSIM is considerably smaller than SIM cards today and should enable the installation of mobile connectivity in a wide range of “secondary” devices and for IoT. Because it allows remote provisioning and switching, eSIM should facilitate the deployment of connected devices in the field as well as supporting switching for personal devices. eSIM will also enable consumers to subscribe to multiple services (profiles) on their device.
- eSIM is present in many devices but is not strongly promoted by mobile service providers. Take-up on handsets is likely to increase with the deployment of smartphones which only accommodate eSIM (already present in the US).

Estimates suggest that around one third of smartphones will be connected via eSIM by 2025. Take-up in industrial devices has been slower, except in cars.

3.1 Key technological and market developments in 5G

3.1.1 5G technology and network deployment

5G refers to the fifth generation of mobile telephony and broadband. In addition to offering higher capacity broadband, the main advantage of 5G compared with 4G/LTE is its potential to enable services which are differentiated by quality, which could support specific use cases in particular for business and various industrial sectors (in this context typically called "verticals"[4]).[5] The main features which are associated with 5G are:

- **Enhanced Mobile Broadband (eMBB)**: Higher capabilities for mobile broadband applications. This mainly includes higher data rates in down and upload.
- **Critical Communications (CC) and Ultra Reliable and Low Latency Communications (URLLC)**: Lower latencies and a higher reliability of service, both important e.g. for remote control of industrial robots. This is one of the main benefits of 5G.
- **Massive Machine-Type Communications (mMTC)**[6]: 5G supports a very high density of devices as is important for certain applications in the IoT.
- **Flexible network operations**: This particularly includes network slicing but also support of devices with different needs regarding mobility (e.g. very stationary and very mobile devices) and with a specific need for energy efficiency.[7]

5G is based on the specifications from 3GPP from release 15 onwards. Release 15 was fully specified in September 2019.[8] Release 16[9] and 17[10] were completed by July 2020 and June 2022, respectively. Release 18, which will reflect the requirements established

4 See e.g BEREC (2022): BEREC report on the 5G Ecosystem, https://www.berec.europa.eu/system/files/2022-10/BEREC%20BoR%20%2822%29%20144%20Report%20on%20the%205G%20Ecosystem.pdf (last accessed on 19.12.22).
5 See ETSI (2019): ETSI TR 121 915 V15.0.0, https://www.etsi.org/deliver/etsi_tr/121900_121999/121915/15.00.00_60/tr_121915v150000p.pdf (last accessed on 19.12.22).
6 mMTC is also known as mIoT (Massive Internet of Things).
7 See ETSI (2021): ETSI TS 122 261 V 16.14.0, https://www.etsi.org/deliver/etsi_ts/122200_122299/122261/16.14.00_60/ts_122261v161400p.pdf (last accessed on 19.12.22).
8 See 3GPP (2022): 5G System Overview, https://www.3gpp.org/technologies/5g-system-overview (last accessed on 19.12.22).
9 See 3GPP (2020): Release 16, https://www.3gpp.org/specifications-technologies/releases/release-16 (last accessed on 19.12.22).
10 See 3GPP (2022): Release 17, https://www.3gpp.org/specifications-technologies/releases/release-17 (last accessed on 19.12.22).

in the IMT-2020 standard,[11] is expected to be released in March 2024[12], and will further develop the 5G features [13] Specifically, release 18 will be the midpoint of 5G releases, and the branding is therefore expected to change to 5G-Advanced. It is envisaged that it will include improvements particularly in upload, support for XR (extended reality) devices and energy efficiency for IoT.

While many features of 5G are yet to be realised, it should be noted that MTC features (massive IoT) are already deployed in many 4G and 5G mobile networks. The network technologies that were specifically designed for IoT, narrowband IoT (NB-IoT) and LTE for machines (LTE-M), both initially started in 4G networks, but can also be considered as 5G technologies as they the KPIs associated with mMTC.[14]

Standalone vs non-standalone deployment

5G networks can be implemented as non-standalone (NSA) and as standalone (SA)[15] networks.[16] For non-standalone networks, the 4G core network is still maintained, while the 5G Radio Access Network (RAN) works on top of it. This only enables some of the eMBB capabilities, i.e. higher data rates, but not the full range of features as described above. Non-standalone 5G can be enabled through spectrum bands designated for 5G as well as those originally assigned for other network technologies (dynamic spectrum sharing). Standalone 5G networks use a designated 5G core network and have the potential to provide all features mentioned above and those still to be released. This includes features relevant for verticals such as URLLC and network slicing.[17]

11 See ITU-R (2021): ITU towards "IMT for 2020 and beyond", https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx (last accessed on 19.12.22).
12 See 3GPP (n.d.): Releases, https://portal.3gpp.org/#/55934-releases (last accessed on 19.12.22).
13 see Qualcomm (2022): Setting off the 5G Advanced evolution, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/setting-off-the-5g-advanced-evolution-with-3gpp-release-18.pdf (last accessed 20.12.22).
14 See Ericsson (2018): Mobile IoT in the 5G future - NB-IoT and LTE-M in the context of 5G, https://www.ericsson.com/assets/local/reports-papers/5g/doc/gsma-5g-mobile-iot.pdf.
15 In this sense "standalone" refers to the independent operation of the 5G network from previous generations. Private networks can be run over either SA or NSA deployments.
16 Standalone in this instance does not mean that these networks are not interconnected to other public networks. The two variants to implement a 5G network are also referred to as "basic" and "full" 5G, some operators also use the marketing terms "5G+", "pure 5G" or "true 5G" to describe standalone 5G.
17 See RC Wireless News (2021): Standalone 5G vs. Non-Standalone 5G, https://www.rcrwireless.com/20210907/5g/standalone-5g-vs-non-standalone-5g (last accessed on 19.12.22).

Spectrum bands for 5G

5G can be delivered using different spectrum bands. The following spectrum bands were designated as "pioneer bands" for 5G to make use of the different functionalities of the standard. For the EU, the following bands were assigned:[18]

- The frequency band from 694 to 790 MHz (**700 MHz band**)
- The frequency band from 3400 to 3800 MHz (**3.6 GHz band**)
- The frequency band from 24.25 to 27.5 GHz (**26 GHz band**)

It is also possible to operate 5G using the same frequencies as are currently assigned to 4G. Dynamic spectrum sharing (DSS) enables the co-existence of 4G and 5G for one network operator in the same frequency band, which enables a new technology without a complete shut-off of the old technology to re-farm the spectrum for the new one.[19]

Characteristics of spectrum bands and implications for investment

The characteristics of the bands (alongside backhaul capabilities) determine the propagation and bandwidths that can be achieved: The lower the frequency, the higher the coverage per antenna; the higher the frequency, the higher the bandwidth and vice versa. This means that to achieve a high geographic coverage, low, sub-1000 MHz bands, are used, while mid-band spectrum (3.6 GHz) is used to support high capacity, but with lower geographic coverage. Millimetre wave (mmWave) spectrum higher than 24 GHz offers very high bandwidth over short distances and is therefore useful for fixed wireless access.[20]

The use of mid-band and millimetre wave spectrum to achieve more advanced 5G capabilities requires the deployment of additional antennas complemented (especially in more densely populated areas) by small cells,[21] to reflect the reduced propagation of these frequencies compared with lower spectrum bands. 5G antennas and small cells

18 See European Commission (2016): Radio Spectrum Committee – Working Document – Mandate to CEPT to develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union, https://circabc.europa.eu/sd/a/448dc765-51de-4fc8-b6e0-56ed6a1d0bca/RSCOM16-40rev3%205G%20draft_mandate_C; Non-European countries did in some cases use adjacent bands, i.e. 5G pioneer spectrum is not completely harmonized around the world, see: https://5gobservatory.eu/5g-spectrum/

19 See Samsung (2021): Dynamic Spectrum Sharing, technical white paper, https://images.samsung.com/is/content/samsung/assets/global/business/networks/insights/white-papers/0122_dynamic-spectrum-sharing/Dynamic-Spectrum-Sharing-Technical-White-Paper-Public.pdf (last accessed on 19.12.22).

20 Potentially this needs to be facilitated through outdoor antennas as mmWave does not penetrate walls well, see e.g. GSMA (2022b): 5G mmWave Deployment Best Practices, https://www.gsma.com/futurenetworks/wp-content/uploads/2022/10/GSMA-5G-mmWave-Deployment-Best-Practices-White-Paper-Nov-2022.pdf (last accessed on 19.12.22).

21 A small cell is a radio access antenna with low power consumption and low costs, that operates with a relatively low range (at most a few kilometres), see https://www.smallcellforum.org/small-cells/.

also need to be connected with fibre,[22] in order to support increasing bandwidth use and low latency requirements. This leads to significantly higher investment requirements for so-called "full 5G" than 5G upgrades which rely on lower frequency bands and do not involve network densification.[23] Full area coverage in Europe with networks with mid-band (3.6 GHz band) or even millimetre wave (26 GHz band) spectrum is therefore unlikely to be economically feasible, and instead a mix of different spectrum bands are likely to be used to reflect different geographic characteristics and bandwidth / QoS requirements.

Analysys Mason[24] estimates that a commercially-driven base case roll-out of 5G by different MNOs using a mix of frequency bands would cost around EUR 150bln for Europe and yield a geographic coverage of more than 80%. A full rollout of one network by deploying the 700 MHz band in the relatively small area not yet served in the base case would cost another EUR 4bln, while covering all areas where there is a need for industry-specific applications (based on URLLC or other 5G SA characteristics) with deployment based on 3.6GHz would cost an additional EUR 20bln.[25]

5G spectrum allocation and usage

As shown in Figure 3-1, while most EEA countries have assigned 5G pioneer spectrum, gaps remain.

22 See e.g. GSMA (2019): 5G-era Mobile Network Cost Evolution, https://www.gsma.com/futurenetworks/wiki/5g-era-mobile-network-cost-evolution/ or the discussion here: Godlovitch, I.; Knips, J.; Wernick, C. (2020): Benefits of the wholesale only model for fibre deployment in Italy, WIK-Consult report for Open Fiber, https://www.wik.org/fileadmin/Studien/2020/Openfiber_wholesaleonly.pdf (last accessed on 19.12.22).

23 See Ockenfels, M.; Eltges, F.; Plueckebaum, T.; Godlovitch, I. (2022): Investment and funding needs for the Digital Decade targets, study for the EC, BCO network, to be published.

24 See Stewart, J.; Nickerson, C. (2021): Costs and benefits of 5G geographical coverage in Europe, Analysys Mason report for Ericsson and Qualcomm, https://www.analysysmason.com/contentassets/81084235a1d9474bb7c0214b68454d58/anaysys-mason-executive-summary-for-5g-geographic-study.pdf (last accessed on 19.12.22).

25 The investment costs projected by Analysys Mason are understood to exclude the costs of securing spectrum. According to the "State of Digital" 2022 report prepared by Analysys Mason for ETNO, total projected costs for 5G spectrum are expected to be around €35bln. This is 10% less than the amount spent on 4G spectrum and 70% less than the €110bln that was invested in securing 3G spectrum. https://5gobservatory.eu/5g-spectrum-costs-in-europe-10-lower-than-4g/

Figure 3-1: Assigned pioneer spectrum bands, 2022

Country	Bands		
	700 MHz	3.6 GHz	26 GHz
Austria	100.00%	97.50%	0.00%
Belgium	100.00%	92.50%	0.00%
Bulgaria	0.00%	75.00%	0.00%
Croatia	100.00%	100.00%	100.00%
Cyprus	100.00%	100.00%	0.00%
Czech Republic	100.00%	100.00%	0.00%
Denmark	100.00%	97.50%	100.00%
Estonia	0.00%	97.50%	0.00%
Finland	100.00%	97.50%	100.00%
France	100.00%	77.50%	70.00%
Germany	100.00%	100.00%	100.00%
Greece	100.00%	97.50%	100.00%
Hungary	83.33%	97.00%	0.00%
Ireland	100.00%	87.50%	0.00%
Italy	100.00%	80.00%	100.00%
Latvia	100.00%	87.50%	0.00%
Lithuania	66.67%	75.00%	0.00%
Luxembourg	100.00%	82.50%	0.00%
Malta	0.00%	75.00%	0.00%
Netherlands	100.00%	0.00%	0.00%
Norway	100.00%	100.00%	0.00%
Poland	0.00%	0.00%	0.00%
Portugal	83.33%	100.00%	0.00%
Romania	0.00%	65.00%	0.00%
Slovakia	100.00%	100.00%	0.00%
Slovenia	100.00%	95.00%	100.00%
Spain	100.00%	95.00%	100.00%
Sweden	66.67%	90.00%	85.00%

Focus countries of this study marked, spectrum not marked as allocated may in some cases be used for other purposes such as wireless local loops; In the Netherlands planning concerning the 3,5GHz band in the Netherlands was changed so that 300 MHz in the 3,5 GHz band is foreseen for mobile use and 100 MHz for local use but the date for the auction has not been set yet. Source: WIK-Consult, based on information collected by the 5G observatory for EU-27[26] and additional information for this study from regulatory authorities.

Six countries have assigned all or almost all of the pioneer bands (Croatia, Denmark, Finland, Germany, Greece and Slovenia) while two countries have not yet assigned the

26 See 5G Observatory (2022): Quarterly Report 17 – October 2022, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf (last accessed on 19.12.22).

3.6 GHz band (Poland and the Netherlands, the latter having assigned the 700 MHz band).[27] Only a few countries have assigned the 26GHz band, which can be used to deliver applications such as FWA and localised high bandwidth connectivity. Reasons vary, but may in some cases be due to limited demand.[28] Some countries such as Belgium have assigned specific spectrum bands for the deployment of private networks.[29]

Non-pioneer bands have also been used for the deployment of 5G, particularly those that are available when phasing out 2G and/or 3G networks. This mainly refers to the 1800 MHz and the 2100 MHz band as well as to a lesser degree the 800 MHz and the 2.6 GHz band. These bands are not able to support the same bandwidths as the 3.6 GHz pioneer band. They do however offer the advantage of a wider area coverage than the pioneer mid-band while also facilitating better mMTC and URLLC features if 5G standalone is deployed. Therefore, non-pioneer bands have the potential to enable some of the benefits of 5G more rapidly than deployments in the 3.6 GHz band. There is a tendency to use these bands in countries where few of the pioneer bands have been assigned such as Poland and the Netherlands but they are also used in France and Germany.[30] The survey for this study among European MNOs also shows a use of the 2100 MHz band by some operators, particularly in the Czech Republic, Spain and Austria. However, not all MNOs use non-pioneer bands for 5G deployment yet.

Commercial launches and coverage

5G has been deployed in all EU countries as well as Norway. However, the degree of coverage varies (see Figure 3-2), depending in part on the date of spectrum awards and the pace of operators' investments.

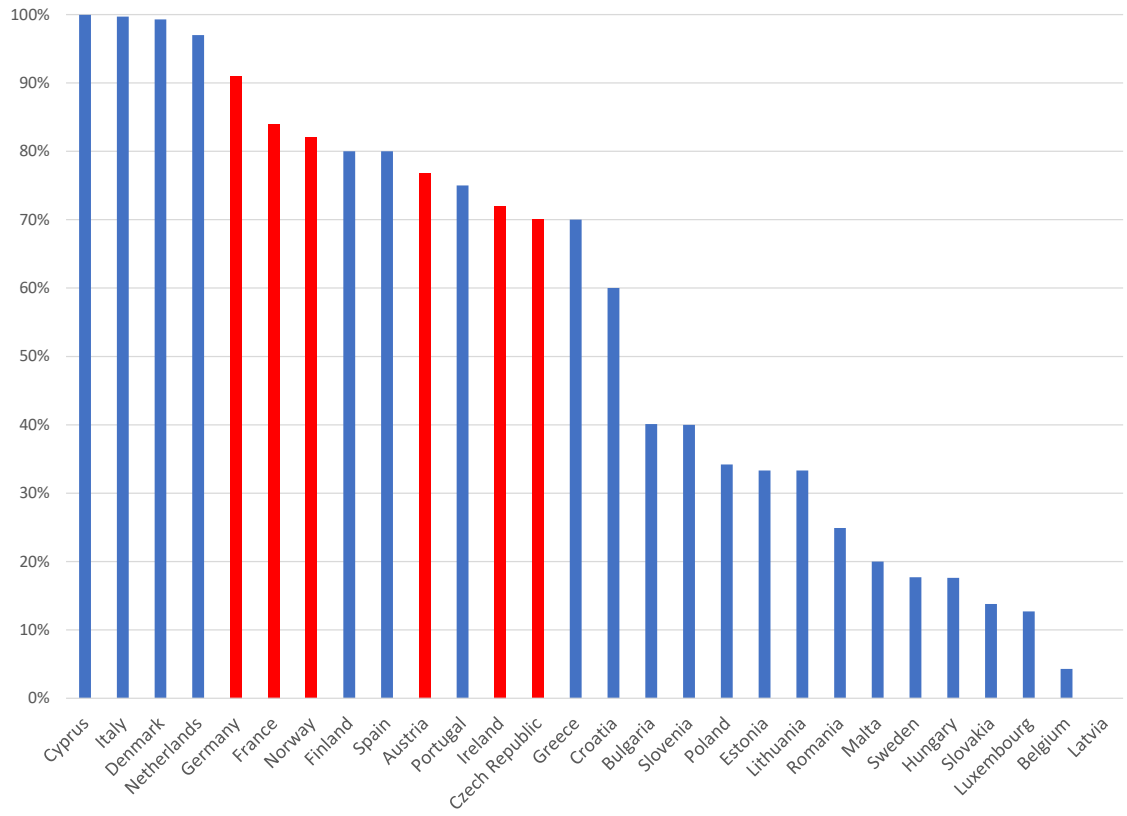
27 To achieve a 100% score, a country needs to assign at least 40 MHz in the 700 MHz band, 400 MHz in the 3.6 GHz band and 1000 MHz in the 26 GHz band, see https://5gobservatory.eu/observatory-overview/eu-scoreboard/

28 For example, ComReg notes that economic operators in the Irish market had not demonstrated a demand to the regulator for assignments in the 26GHz, and thus the regulator intends to continue to monitor developments before making bands available for efficient use.

29 Belgium has assigned 3800-4200 MHz for this purpose.

30 See 5G Observatory (2022): Quarterly Report 15 – March 2022, https://5gobservatory.eu/wp-content/uploads/2022/05/5G-Observatory-Quarterly-Report-15-May-2022.pdf (last accessed on 19.12.22).

Figure 3-2: Population/household31 coverage of 5G, newest available data (where available: Q3 2022)



Focus countries marked in red; The 0% figure in Latvia is due to no available recent data, there have been commercial deployments of 5G in the country. Source: WIK-Consult based on information collected by the 5G observatory and NRAs[32]

The first non-trial[33] launch of a 5G network in Europe was conducted by the mobile operator Elisa in Tampere (Finland) and Tallinn (Estonia) in Mid-2018.[34] By Mid-2020, half of all countries covered by the 5G observatory (EU-27 + UK) had a live commercial 5G service, while in four countries (Austria, Finland, Romania, UK) three or more operators had already deployed their network.[35] Since January 2022, 5G has been

31 The 5G Observatory reports coverage based on population or household coverage depending on the source used.

32 See 5G Observatory (2022): Quarterly Report 17 – October 2022, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf (last accessed on 19.12.22).

33 As no 5G smartphones were publicly available at that point, this still had the spirit of a trial but was reported as the first commercial launch.

34 See 5G Observatory (2018): Quarterly Report 2 – December 2018, http://5gobservatory.eu/wp-content/uploads/2019/01/80082-5G-Observatory-Quarterly-report-2-V2.pdf (last accessed on 19.12.22).

35 See 5G Observatory (2020): Quarterly Report 8 – June 2020, http://5gobservatory.eu/wp-content/uploads/2020/07/90013-5G-Observatory-Quarterly-report-8_1507.pdf (last accessed on 19.12.22).

offered by at least one operator in all EU member states, with Lithuania as the last addition.[36] Available literature and experience with the deployment of previous generations of mobile technology, suggest a timeframe of around 5 years for the deployment of basic 5G (on lower frequencies),[37] which would mean that full population coverage of 5G is expected to be largely complete by 2025/6.[38] However, the vast majority of these 5G deployments will be "non-standalone", which means that while bandwidths have increased, the full capabilities of 5G will not be available through this upgrade.

A few operators across Europe have now started deploying 5G standalone networks, often starting with small areas as a test space. The first 5G standalone core was deployed by Vodafone Germany together with Ericsson in April 2021.[39] In November 2021, Telia launched a 5G SA network in 20 areas in Finland, facilitated by Nokia.[40] Orange followed suit in September 2022 by rolling out such a network in Belgium with different networking partners.[41]

Hutchison 3 in Austria launched their 5G standalone offer in October 2021 for a part of the country. They explicitly use network slicing to be able to guarantee certain bandwidths in their fixed wireless product.[42] The 5G SA products are priced around the same range as their 4G and 5G non-standalone counterparts[43] and guarantee half of the advertised

36 See 5G Observatory (2022): Quarterly Report 14 – January 2022, https://5gobservatory.eu/wp-content/uploads/2022/02/5G-Obs-PhaseIII_Quarterly-report-14_FINAL-Clean-for-publication_16022022.pdf (last accessed on 19.12.22).

37 Analysys Mason (2021) Costs and benefits of 5G geographical coverage in Europe https://www.analysysmason.com/consulting-redirect/reports/filling-europes-5g-coverage-gaps/) notes that there are likely to be successive phases in the deployment of 5G, as MNOs gradually expand capacity and upgrade the network to meet demand. Specifically, Analysys Mason expects deployment of 2.6GHz, 1400MHz and 2300MHz spectrum for 5G on a portion of existing sites (60% of sites, from different points in time in the network, starting with 2024 for 2.6GHz, then 2025 for 2300MHz and 2026 for 1400MHz). They note that they expect that deployment on these spectrum bands will be phased across 2-3 years from the initial date specified.

38 See for example https://spectrummattersindeed.blogspot.com/2020/10/which-demand-curve-for-5g-3g-or-4g.html - citing JHA, Saha. This expectation is confirmed by a 2021 study for Ericsson and Qualcomm by Analysys Mason (https://www.analysysmason.com/consulting-redirect/reports/filling-europes-5g-coverage-gaps/) which suggests that 700MHz will be deployed across the entire grid in all countries by 2026, achieving more than 99% population coverage and more than 80% geographical coverage. They suggest that most of the costs for the deployment of enhanced mobile broadband (eMBB) will have been incurred by 2025/26.

39 See Ericsson (2021): Shaping Germany's 5G future – Vodafone's deployment of Europe's first 5G standalone core network, https://www.ericsson.com/en/cases/2021/vodafone-and-ericsson (last accessed on 19.12.22).

40 See 5G Observatory (2021): Telia and Nokia launch standalone 5G in Finland, https://5gobservatory.eu/telia-and-nokia-launch-standalone-5g-in-finland/ (last accessed on 19.12.22).

41 See 5G Observatory (2022): Orange Belgium deploys Standalone 5G, https://5gobservatory.eu/orange-belgium-deploys-standalone-5g/ (last accessed on 19.12.22).

42 See Planet Drei (2021): 5G Standalone: Was der neue Mobilfunkstandard alles kann. https://www.drei.at/de/planet-drei/blog/artikel/5g-standalone.html (only available in German, last accessed on 19.12.22).

43 The offers are not directly comparable as 3 offers a different portfolio with higher bandwidths for 5G standalone products. Moderately higher bandwidths are offered for moderately higher prices. The

maximum bandwidth by utilizing network slicing.[44] According to information from the 5G observatory, standalone deployments are planned or have been initiated in several other EU countries as well (e.g. Spain, Italy, Denmark).[45]

5G Standalone networks are currently more common in private than in public networks, as the former often have to be built from the ground up and are condensed in a relatively small and segregated space. Some examples are the Skoda factory in Mladá Boleslav that is supplied with a 5G SA network by Vodafone Czech Republic[46] and the broadcast which was made by TV2 for the Danish parliament elections.[47]

There is however an ongoing "chicken-and-egg" problem of device support for new features. Vodafone Germany conducted a live stream from a moto race at the Nürburgring based on network slicing. However, this was done through 4G due to lack of devices supporting 5G SA.[48]

Considering the different spectrum bands and technological deployment methods (standalone vs. non-standalone) used, there are few reliable projections on when 5G coverage will be complete and on which frequencies/which type of 5G.[49] The current (Q3 2022) population/household coverage in the EU-27 estimated by the 5G observatory is 72%, up from 66% reported in a study for the EU commission in Mid-2021.[50] However, these values only reflect the proportion of households covered by at least one operator independent of spectrum band and standalone vs. non-standalone. A model by Analysys Mason suggests that 30-60% of the population could be commercially served with

standard 4G/5G products can be found here: https://www.drei.at/de/shop/tarife/privat/internet-tarife/tarife-fuer-zuhause/; the ones with 5G standalone are found here: https://www.drei.at/de/shop/tarife/privat/internet-tarife/tarife-fuer-zuhause/bandbreiten-garantie.html

44 This guarantee only holds if the customer uses the equipment that 3 recommends, which could also be an outdoor router/antenna, depending on the location.

45 See 5G Observatory (n.d.), Overview of commercial 5G launches, https://5gobservatory.eu/overview-5g-commercial-launches/ (last accessed on 19.12.22).

46 See Wood, N. (2022): Voda gives Skoda its very own private 5G SA network, https://telecoms.com/516116/voda-gives-skoda-its-very-own-private-5g-sa-network/ (last accessed on 19.12.22).

47 See Neutral Wireless (2022): Standalone 5G Private Network Live in Copenhagen with TV2 for the Danish Elections, https://www.neutralwireless.com/2022/11/danish-election/ (last accessed on 19.12.22).

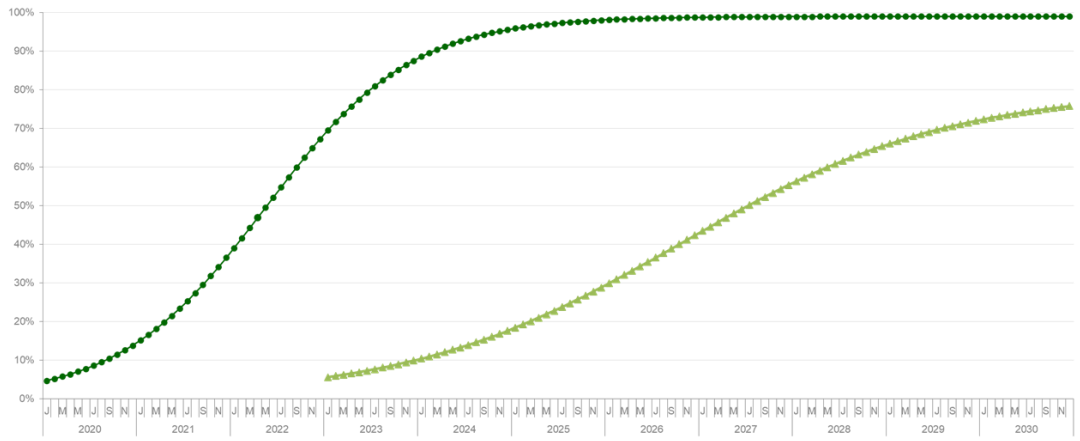
48 See 5G Observatory (2022): Vodafone Germany trials network slicing, https://5gobservatory.eu/vodafone-germany-trials-network-slicing/ (last accessed on 19.12.22).

49 There can be a debate on what "complete" means, e.g. if a rollout only in sub-1GHz spectrum can be considered a "complete 5G rollout" for all use cases.

50 The 5G observatory takes the values from the study and updates them for countries where newer data is available. So it reflects a partial update of this number, the coverage increase from Mid-2021 to Q3 2022 was likely higher. Sources: 5G Observatory (2022): Quarterly Report 17 – October 2022, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf and IHS Markit, OMDIA, Point Topic (2022), Broadband Coverage in Europe 2021, study for the European Commission, https://digital-strategy.ec.europa.eu/en/library/broadband-coverage-europe-2021 (last accessed on 19.12.22).

standalone 5G mid-band spectrum (3.5/3.6 GHz band),[51] while a projection by WIK-Consult for the European Commission estimates that 5G based on mid-band spectrum could reach around 65% coverage by 2030.[52]

Figure 3-3: WIK projection for 5G deployment (eMBB in dark green, 3.5/3.6 GHz 5G in light green), in % of population



Source: WIK-Consult.[53]

According to interviews for this study, market participants estimate that 5G standalone deployment will start around 2023 and will become more widespread by the mid-2020s, which appears to be a reasonable assumption considering that coverage of non-standalone 5G should be largely complete by then, and demand for quality-assured services is expected to emerge around that time.

Extensive geographic coverage is harder to achieve than population coverage. However, in the long run, 5G will cover all or almost all geographic areas of the EU, in the same way as 4G does currently. It is expected that the coverage in less densely populated areas will be provided through sub-GHz bands, which provide good coverage and are

51 See Stewart, J.; Nickerson, C. (2021): Costs and benefits of 5G geographical coverage in Europe, Analysys Mason report for Ericsson and Qualcomm, https://www.analysysmason.com/contentassets/81084235a1d9474bb7c0214b68454d58/anaysys-mason-executive-summary-for-5g-geographic-study.pdf (last accessed on 19.12.22).

52 While it is widely expected that near-full basic 5G coverage will be achieved by 2025/6, the timeframe for the deployment of "full 5G" involving increased use of 3.6GHz band, SA deployment and network densification is less clear. Deployment is expected to expand from 2023 onward, but MNOs have not provided concrete indications regarding the pace of deployment and target coverage.

53 See Godlovitch, I; Kroon, P.; Strube Martins, S.; Schaefer, S.; Lucidi, S.; Steffen, N.; Ockenfels, M.; Plückebaum, T.; Schwarz-Schilling, C., Herrera, F.; Juskevicius, R.; Pasquali, F.; Tambjerg, L. (2023): Support study accompanying the Review of the Broadband Cost Reduction Directive: Impact Assessment, Final Report, https://op.europa.eu/en/publication-detail/-/publication/7f14b774-b71a-11ed-8912-01aa75ed71a1/language-en (last accessed on 13.03.2023).

expected to be sufficient to meet the estimated level of demand in these areas.[54] 3.6GHz frequencies are mainly used where there is higher bandwidth demand, i.e. in densely populated areas and along traffic lanes (highways and railway lines). For areas in between those served with the need for 3.6GHz and those adequately served with sub-GHz frequencies, spectrum bands such as the 1800 MHz band are already in use in some countries. 26GHz may also be used in areas with very high population density or high bandwidth demand (e.g. events venues) as well as for private networks in some use cases. 26 GHz is also likely to be used for FWA applications including in very remote areas, where FTTP connectivity may not be economically viable.

5G SA (which involves the upgrade of the core network so that it operates independently from 4G) does not require the use of the 3.6GHz band. However, higher frequencies strengthen its advantages, particularly those of enhanced bandwidths, further. 5G SA is likely to be deployed in parallel to the 3.6 GHz rollout displayed in Figure 3-3 but as it will cover all base stations in the long run (considering that 4G will be switched off at some point), it will reach more than the 60% 3.6 GHz coverage analysts estimate will be provided on a commercial basis.

Private 5G networks and network slicing

Alongside public 5G networks, organisations may decide to implement private 5G networks[55] or upgrade their existing private networks (based on 4G/WiFi/other technologies) to 5G. These private networks can be tailored to the needs of the enterprise or "vertical" using it. Typically, these private networks cover a limited area (e.g. an industrial area, hospital or entertainment venue). However, this depends on the spectrum used: they can also utilize other frequencies with widespread propagation (e.g. in the 450 MHz band for energy networks).

5G private networks can be set up by MNOs allocating a portion of the spectrum they have been granted through auctions to a specific location/vertical. One option for MNOs to implement such a private network will be through network slicing, which is explained below. Some countries such as Germany (see section 6.1.3 for a more detailed discussion) have decided to grant spectrum directly to verticals. If verticals use their own spectrum licenses, they can either build their private network themselves or request support from MNOs, MVNOs or other specialized network providers.[56] If the company has no legacy mobile infrastructure that needs to be included in the private network, they

54 See e.g. for Germany: Zoz, K.; Plückebaum, T.; Sörries, B.; Elbanna, A. (2022): Abschätzung des Bedarfs an 5G Mobilfunkstandorten für den Frequenzbereich von 3,6 GHz zur Füllung von Lücken zwischen den bestehenden Mobilfunkstandorten, WIK research brief, available only in German: https://www.wik.org/uploads/media/WIK_Kurzstudie_3-6GHz-Standortbedarf.pdf.

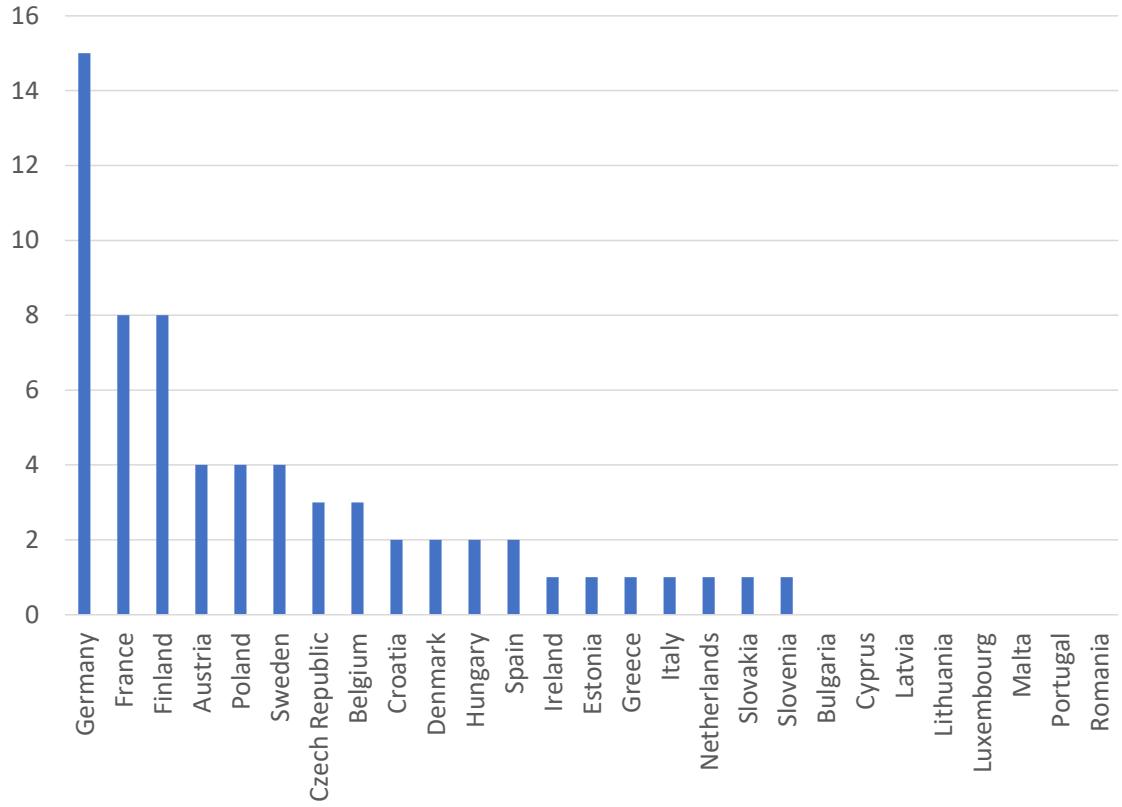
55 In the context of 5G, these networks are technically called Non-Public Networks (NPN).

56 For more information on thee implementation scenarios and the conjunction of 5G private networks to public networks, see 5G ACIA (2019): 5G Non-Public Networks for Industrial Scenarios, White Paper, July 2019, https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf

are typically implemented as standalone networks to grant access to all functionalities of 5G.

A rough indication regarding deployments of 5G private networks can be found in Figure 3-4 below. It includes private 5G networks built in cooperation with an MNO using its spectrum. This is based on information manually gathered (e.g. by screening press releases) by the 5G observatory of the EU, thus de facto signalling the lower boundary of such private networks. The real number is estimated to be significantly higher.[57]

Figure 3-4: Number of publicised private 5G networks per country by December 2022[58]



Source: WIK-Consult based on data from the 5G observatory59

57 A recent report by the suppliers association GSA counts almost 1,000 worldwide private mobile networks: GSA (2022): Private Mobile Networks – December 2022 Summary Report, https://gsacom.com/paper/private-mobile-networks-december-2022-summary-report/ (last accessed on 19.12.22).

58 This represents only private networks publicised e.g. through press releases, which have been recorded by the EU 5G Observatory.

59 See 5G Observatory (n.d.): 5G private networks, https://5gobservatory.eu/5g-private-networks/ (last accessed on 19.12.22).

The relatively large number of private networks in Germany is likely linked to the strategy by the regulator to award spectrum for verticals in the 3.7-3.8 GHz range for the purpose of deploying private networks.[60] The Bundesnetzagentur also awards frequencies in the 26 GHz range for local uses.[61] By November 2022, 265 licenses for local networks in the 3.7-3.8 GHz range had been awarded (269 have been requested)[62], while there were 15 awards in the 26 GHz range.[63] The awards are technology neutral. Some licenses are used for testing purposes and there is no requirement for immediate deployment but this does suggest that the number of private 5G networks in Germany is likely to be far higher than the 15 examples gathered by the 5G observatory. The numbers are however still yet to reach the potential that was estimated in 2020 in the guidelines for 5G campus networks by the German Ministry for Economic Affairs and Energy of 5000 – 10000 of these networks by 2025.[64]

Another possibility to implement the benefits of 5G particularly (although not only) for industrial customers is network slicing. Network slicing is the practice of enabling multiple virtualized independent networks on one technical infrastructure. This allows for a differentiation of quality parameters in the different slices within a physical network.[65] This includes but is not limited to URLLC (real time communication), very stable and reliable bandwidth (high quality-of-service, QoS) and efficient energy usage to facilitate

60 See Bundesnetzagentur (2021): Administrative rules for spectrum assignments for local spectrum usages in the 3700-3800 MHz band (Administrative rules for local broadband applications) – courtesy translation, https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/FrequencyAssignment/LocalBroadband3,7GHz.pdf?__blob=publicationFile&v=2 (last accessed on 19.12.22).

61 See Bundesnetzagenturr (2021): Administrative rules for spectrum assignments for local broadband spectrum usages in the 24.25-27.5 GHz band (Administrative rules for local broadband applications at 26 GHz) – courtesy translation, https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/FrequencyAssignment/LocalBroadband26GHz.pdf?__blob=publicationFile&v=2

62 See Bundesnetzagentur (2022): Übersicht der Zuteilungsnehmer für Frequenzzuteilungen für lokale Frequenznutzungen im Frequenzbereich 3.700-3.800 MHz, https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/LokaleNetze/Zuteilungsinhaber3,7GHz.pdf?__blob=publicationFile&v=27 (available in German only, only organisations listed which agreed to be listed, last accessed on 19.12.22).

63 See Bundesnetzagentur (2022): Übersicht der Zuteilungsinhaber für Frequenzzuteilungen für lokale, breitbandige Frequenznutzungen im Frequenzbereich 24.250-27.500 MHz, https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/LokaleNetze/Zuteilungsinhaber26GHz.pdf?__blob=publicationFile&v=19 (available in German only, only organisations listed which agreed to be listed, last accessed on 19.12.22).

64 The number was estimated by Nokia, which was one of the main contributors to the guidelines, see Federal Ministry for Economic Affairs and Energy (2020): Guidelines for 5G Campus Networks – Orientation for Small and Medium-Sized Businesses, https://www.bmwk.de/Redaktion/EN/Publikationen/Digitale-Welt/guidelines-for-5g-campus-networks-orientation-for-small-and-medium-sized-businesses.pdf?__blob=publicationFile&v=2 (last accessed on 19.12.22).

65 While some of this potential can also be achieved in 4G networks, the possibilities in 5G (standalone) networks are far more sophisticated.

device battery life and also allows the separation of networks with higher security requirements from those without.[66] In a non-sliced physical network, there need to be trade-offs between different parameters while a network slice can be concentrated on the specific use case and its requirements.

In general, tailored network slices can enable the same use cases as private networks. In addition, they support quality-assured service over a wider geographic area than a private network that is deployed within a limited footprint. MNOs consider that network slicing could offer an alternative solution to smaller companies that do not have the scale to develop their own private networks through acquiring or leasing spectrum, or to companies which require quality-assured services with widespread coverage. It is also open for companies to seek to develop use cases via the "best-effort" Internet if they have no access to private spectrum and are not large enough to warrant the implementation of network slicing procedures or to lease spectrum.

While a key focus for MNOs is to deploy network slicing directly to business end-users, network slicing could also have wholesale applications. If MVNOs can gain access to specific network slices, they could tailor their services to specific customer groups, e.g. by purchasing access only to very critical slices to facilitate industrial verticals or by only accessing "best-effort" slices to address low-cost mass-market customers.[67]

Voice over 5G

The provision of voice calls and messaging can also be enabled over 5G.[68] Like VoLTE, VoNR makes use of an IP multimedia subsystem (IMS) as the basis for offering calls. The quality parameters of such voice calls are not vastly different than for voice over LTE (VoLTE) but enables voice to be provided without needing to maintain legacy technologies. New applications could also be enabled by 5G through a better connection of voice and data channels. This could make services such as simultaneous language translation or live assistance more feasible.[69] With 5G non-standalone networks, it is not possible to use data connections through 5G while calling using this technology. Thus legacy technologies need to be maintained for the calling functionality. This will however be possible with standalone 5G networks.[70]

66 See GSMA (2017): An Introduction to Network Slicing, https://www.gsma.com/futurenetworks/wp-content/uploads/2020/01/1.0_An-Introduction-to-Network-Slicing.pdf (last accessed on 19.12.22).
67 See telecoms.com (2018): How 5G will revolutionise the MVNO market, https://telecoms.com/opinion/how-5g-will-revolutionise-the-mvno-market/ (last accessed on 19.12.22).
68 As the radio technology behind 5G is also referred to as 5G New Radio (5G NR), voice over 5G is also known as VoNR (voice over new radio).
69 See GSMA (2021a): IMS Data Channel White Paper, https://www.gsma.com/newsroom/wp-content/uploads//NG.129-v1.0-1.pdf (last accessed on 19.12.22).
70 See Ericsson (2022): Voice and communication services in 4G and 5G networks, https://www.ericsson.com/4a19c3/assets/local/reports-papers/white-papers/voice-and-communication-services.pdf (last accessed on 19.12.22).

5G calling is not live in the vast majority of markets, although T-Mobile US has started it in Portland and Salt Lake City in June 2022.[71] In Europe there have been trials from Deutsche Telekom[72] and a small scale rollout by Telefónica Germany in 2021.[73]

3.1.2 Mass-market use cases

The main benefit for consumers from 5G is eMBB, i.e. higher broadband data rates. Other quality advantages of 5G that can only be achieved with standalone networks include support for consumer services in certain specific situations. For example, 5G can facilitate a better experience at events due to higher capacity of networks and a better support for a large number of devices.[74] Customers could also benefit from lower latencies, e.g. for cloud gaming and live driving-assistance systems in their cars.

Customers using mobile networks as a replacement for fixed networks (Fixed Wireless Access) also benefit from higher bandwidths but particularly from guaranteed speeds that can be facilitated by 5G. Three Austria offers such a product based on 5G standalone in certain areas and guarantees a certain bandwidth, similar to guaranteed bandwidths in fixed networks. This is realized by utilizing network slicing and assigning a specific slice to these applications.[75]

The interviews and surveys for this study show that some market participants see even further potential for network slicing for the mass-market in the future. This could include additional service / tariff options for customers with the need for guaranteed network bandwidth, e.g. for business customers who want to access video conference tools, while normal video traffic (for entertainment purposes) is served on a “best-effort” basis for those without these extra tariffs. Tailored products could potentially also be offered for video gamers and other kinds of customer groups. It may also be possible for the customer to decide, in case they have more than one tariff booked, to assign certain applications to use certain tariffs with a different network slice, i.e. with a different service

71 See Segan, S. (2022): In These 2 Cities, You Can Finally Make Phone Calls Over 5G, https://uk.pcmag.com/old-wireless-carriers/140720/in-these-2-cities-you-can-finally-make-phone-calls-over-5g (last accessed on 19.12.22).

72 See Deutsche Telekom (2021): World first end to end multivendor 5G Voice over NR call, https://www.telekom.com/en/media/media-information/archive/world-first-end-to-end-multivendor-5g-voice-over-nr-call-628746 (last accessed on 19.12.22).

73 See Telefónica Germany (2021): O_2 succeeds in making Germany’s first voice call on the 5G live network, https://www.telefonica.de/news/press-releases-telefonica-germany/2021/09/voice-over-new-radio-vonr-o2-succeeds-in-making-germanys-first-voice-call-on-the-5g-live-network.html (last accessed on 19.12.22).

74 See Nokia (n.d.): How 5G will transform live events, https://www.nokia.com/networks/insights/how-5g-will-transform-live-events/ (last accessed on 19.12.22).

75 Three offers bandwidths with a maximum of 100, 150, 250 and 500 Mbps download speed and guarantees half of that bandwidth at all times, see Sokolov, D. (2022): Garantierte Mobilfunk-Bandbreite erstmals für Privatkunden: Hutchison 3 Austria, https://www.heise.de/news/Garantierte-Mobilfunk-Bandbreite-erstmals-fuer-Privatkunden-Hutchison-3-Austria-7280286.html (last accessed on 19.12.22).

quality and potentially a different price. On the other hand, this opens up the possibility for more cost-sensitive customers to only use a less expensive "best-effort" product.[76]

According to the Ericsson Mobility Report[77], only 6% of European[78] smartphone mobile subscriptions currently have access to 5G in 2022, while 90% have 4G/LTE access. In the more technologically advanced subregion of Western Europe, 11% can use 5G. The absolute number of subscriptions with 4G access (or less) is projected to have peaked and is expected to decline. By 2028, 70% of smartphone subscription in Europe are estimated to have access to 5G, leaving only a minority without access to the newest network technology. In Western Europe this number is estimated to be at 90%.

Statistics provided by the mobile operator's association GSMA broadly confirm these estimations. The GSMA observed that 4% of subscriptions in Europe were on the basis of 5G in 2021, and this is projected to increase to 44% by 2025.[79]

The market for 5G-capable handsets is also moving fast, and may be linked to the marketing of 5G services. A survey by Ericsson in 2021[80] and 2022[81] shows that there was an increase in customers with 5G-ready devices within the markets where 5G had been launched from 4% to 13%. However, for the European countries surveyed, the dynamic was less strong, in 2022 the share of customers with 5G devices stood between 4% (Belgium, Finland) and 11% (Italy). This seemingly low number likely constitutes a lower boundary for 5G handset ownership as a share of customers may not know that they have a device which is theoretically able to utilize 5G.

The average lifetime of a smartphone sold in Europe is around three years.[82] The number of smartphones newly shipped that are 5G-enabled was estimated to be around 50% in

76 This may pose concerns regarding net neutrality, which would need to be observed on a case-by-case basis, see: BEREC (2018): BEREC Opinion for the evaluation of the application of Regulation (EU) 2015/2120 and the BEREC Net Neturality Guidelines, https://www.berec.europa.eu/sites/default/files/files/document_register_store/2018/12/BoR%20%2818%29%20244_BEREC_Opinion_NN_evaluation_.pdf (last accessed on 19.12.22).

77 See Ericsson (2022): Ericsson Mobility Report, November 2022, https://www.ericsson.com/4ae28d/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-november-2022.pdf (last accessed on 19.12.22).

78 This encompasses the regions „Western Europe" and "Central & Eastern Europe" in the Ericsson Mobility Report, thus including Non-EU countries such as the UK, Ukraine and Russia.

79 See GSMA (2022): The Mobile Economy 2022, https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/02/280222-The-Mobile-Economy-2022.pdf (last accessed on 19.12.22).

80 See Ericsson (2021): Five ways to a better 5G – Key trends influencing consumer adoption of 5G, https://www.ericsson.com/49944f/assets/local/reports-papers/consumerlab/reports/2021/five-ways-to-a-better-5g-report.pdf (last accessed on 19.12.22).

81 See Ericsson (2022): Percentage of consumers who own a 5G capable smartphone in 2022, In: Statista, https://www.statista.com/statistics/1236180/percentage-5g-subscription-5g-smartphone-by-country/ (last accessed on 19.12.22).

82 See Coolproducts (2019): Coolproducts don't cost the earth, https://eeb.org/wp-content/uploads/2019/09/Coolproducts-briefing.pdf (last accessed on 19.12.22).

2022 and this is expected to increase to 70% in 2023.[83] As this figure is for worldwide shipments, the share in Europe will likely be higher due to the advanced market. We can therefore estimate that by 2024/2025 nearly all new smartphones in the developed world will be sold with 5G modules and a (slight) majority of customers will use such a device by then. Device take-up should therefore not be a significant barrier to 5G take-up in the mass market[84], except potentially for "vulnerable" customers that are particularly dependant on low-price smartphone models and/or have very long use times for their device.

According to the interviews for this study, the number of customers without 5G handsets is higher for operators with more cost-sensitive customers (i.e. typically MVNOs and especially those with a lot of pay-as-you-go customers). This corresponds with the device replacement rates and lifetimes as analysed above. Some operators even have a significant share of customers with handsets that do not even support 4G. For the latter, the progressive switch-off of 2G/3G networks may pose an additional challenge.

3.1.3 Business use cases

Many of the benefits of 5G are particularly relevant for industrial, or "vertical", use cases. While higher data rates (eMBB) can also be helpful to transfer data rapidly in industrial settings, most advantages come from the other 5G benefits. To reap these benefits, standalone deployments of 5G are needed.

Communication that is ultra-reliable and offers next to no latency (URLLC) enables sensitive applications such as remote control of robots in manufacturing and healthcare. Massive deployment of sensors for dense cities and factories is another use case in the IoT, which benefits from (standalone) 5G. Automotive connectivity (Vehicle-to-everything, V2X) is also facilitated through 5G as only this technology can offer real-time sensor technology and potentially remote driving or cloud-based autonomous driving.[85]

For locally defined purposes, private (also called campus) networks enabled by 5G can help to reap the benefits of the new technology. These local networks have the benefits of a high potential degree of customization and that there is no need to work with "best-

83 See Canalys (2021): Canalys: Smartphone shipments set to grow 12% in 2021, despite supply pressure, https://canalys-prod-public.s3.eu-west-1.amazonaws.com/static/press_release/2021/82116113Canalys_Smartphone_shipments_set_to_grow_despite_supply_pressure.pdf (last accessed on 19.12.22).

84 In the transitional period to a "full 5G world", there may be a partial issue with devices not supporting all potential 5G spectrum bands or not supporting standalone 5G, this issue does however diminish rapidly. In mid-2022, 90% of new 5G devices also supported standalone 5G: Wood, N. (2022): Nearly 90 percent of new 5G devices support standalone, https://telecoms.com/516316/nearly-90-percent-of-new-5g-devices-support-standalone/ (last accessed on 19.12.22).

85 See NGMN Alliance (2018): V2X White Paper, https://5gaa.org/wp-content/uploads/2018/08/V2X_white_paper_v1_0.pdf (last accessed on 19.12.22).

effort" based networks by MNOs. Some of these benefits could however also be achieved by network slicing or spectrum leasing.[86]

It should also be noted that 5G-specific technology is not required for all business use cases. Narrowband IoT technologies (NB-IoT) in cellular networks also play an important role for IoT connectivity, specifically for massive machine type communications with low-energy consumption and low bandwidth requirements. They can be seen as a relevant enabler for many use cases that involve sending low amounts of data over a long range such as smart metering, asset tracking, supply chain management. NB-IoT competes with other LPWAN (Low power wide area networks) technologies that can be realized using license-free spectrum (e.g. used by Sigfox and LoRaWAN). The development of narrowband in public mobile networks (NB-IoT, LTE-M) has only gained momentum in the last 2-3 years. According to Kaleido, 9% of all IoT connections were based on NB-IoT and LTE-M in 2020 and are expected to increase to 41% in 2027.[87]

3.2 eSIM developments

3.2.1 What is eSIM?

The SIM card is a tamper resistant microprocessor card with an operating system, storage and build-in security features. It contains the International Mobile Subscriber Identity (IMSI) as well as credentials that are necessary for the identification and authentication of the subscriber to enable connection to the mobile network. The SIM card prevents unauthorized individuals from accessing, retrieving, copying, or modifying the subscriber's IMSI and credentials.

The embedded SIM (eSIM, also embedded Universal Integrated Circuit Card (eUICC) is a permanently installed variant of the SIM card. Alternatively, it is possible to realise the eSIM functionality as a software solution. In this case, instead of separate eSIM hardware, the data and keys stored on the SIM are stored in the memory, processor or operating system.[88]

86 See GSMA (2022): Spectrum leasing in the 5G era, https://www.gsma.com/spectrum/wp-content/uploads/2022/01/Spectrum-Leasing-5G-Era.pdf (last accessed on 19.12.22).

87 See Kaleido (2023), Navigating beyond Connectivity: IoT MVNO Landscape & Outlook, Presentation for MWC MVNO Summit 2023, https://www.gsma.com/membership/wp-content/uploads/2022/10/Keleido-2023-MVNO.pdf, slide 5.

88 See Gries, C.-I. and Wernick, C. (2017): Bedeutung der embedded SIM (eSIM) für Wettbewerb und Verbraucher im Mobilfunkmarkt, WIK Diskussionsbeitrag Nr. 422, Bad Honnef; Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 04.12.2022); GSMA (2018): eSIM Whitepaper, The what and how of Remote SIM

The eSIM contains the same information as the SIM card for identification and authentication between subscriber and mobile network. However, the eSIM additionally enables the distribution of digital eSIM profiles through Remote SIM Management (RSM) and Remote SIM Provisioning (RSP) capabilities, i.e. Over-the-Air (OTA) provisioning. This means that a customer can switch operator without physically changing the SIM card. The distribution of digital eSIM profiles requires a specific IT architecture on the operator's side and a device equipped with an eSIM for remote SIM provisioning via the OTA interface.

The implementation of the eSIM allows the user to set up multiple provider profiles. This means that several mobile phone providers can be used in parallel (comparable to dual SIM, but without having to insert multiple physical SIMs). In theory this means that it should be possible for a user to make use of different subscriptions at the same time. However, under current eSIM standards, this is not yet seamless as users need to switch between profiles.

The latest stage of the eSIM evolution is the integrated SIM (iSIM) which integrates the SIM directly into the device's processor. The iSIM enables devices to connect to a cellular network without needing a physical SIM card or soldered eSIM in a printed circuit board. Similarly to eSIM, the iSIM saves space by eliminating the need for a separate component, allowing for the secure connection of smaller devices. However, according to SIM providers, it requires significantly less power than eSIMs, making, for example, massive IoT use cases more operational.[89]

Provisioning, https://www.gsma.com/esim/wp-content/uploads/2018/12/esim-whitepaper.pdf (last accessed on 04.12.2022).

89 https://www.thalesgroup.com/sites/default/files/database/document/2021-07/tel-info-ISIM.pdf; https://www.gi-de.com/en/connectivity/mobile-network-operator/integrated-sim#:~:text=Also%20known%20as%20an%20Integrated%20SIM%20%28iSIM%29%2C%20iUICC,of%20potential%20and%20advantages%20for%20the%20IoT%20industry; https://www.thalesgroup.com/en/markets/digital-identity-and-security/mobile/connectivity/isim

Table 3-1 provides an overview of the main differences between traditional, physical SIM cards and eSIMs.

Table 3-1: Differences between physical SIM card and eSIM

Traditional SIMs (Universal Integrated Circuit Card UICC)	eSIMs (embedded Universal Integrated Circuit Card eUICC)
Carrier specific & contains only one carrier profile	Operator or OEM (Original Equipment Manufacturer) specific but can support multiple carrier profiles
Carrier profile cannot be replaced remotely	Remote download & management of additional carrier profiles possible
Physical SIM swap is required to change carriers	Eliminates physical SIM swaps. Over-the-air profile management
Different SIM for each carrier	One SIM for multiple carriers

Source: Baischew, D. et al. (2021).[90]

3.2.2 How is the market developing?

eSIM is still at an early stage, but is developing rapidly. While eSIM technology was initially developed for the M2M market, it is now far more advanced in the consumer market. Overall, eSIMs are being integrated into an increasing number of devices for a wide range of applications.[91] In 2021, a total of 350 million eSIM units were shipped.[92] Current growth is mainly driven by the launch of new eSIM-enabled smartphone models and smartwatches. According to a global survey by Truphone (2021), smartphones are regarded as the most well-suited for eSIM by MNOs and device manufacturers (followed by cars and smartwatches).[93]

The number of eSIM-enabled smartphones is steadily increasing (see Figure 3-5). Premium smartphones in particular now generally have eSIM functionality. The GSMA expects an acceleration of the penetration with eSIM-capable devices from 2023 onwards

90 Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 04.12.2022).

91 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 04.12.2022)

92 Counterpoint Research. (July 13, 2022). Cumulative number of eSIM-capable device shipments worldwide from 2021 to 2030 (in billions) [Graph]. In Statista. Retrieved December 19, 2022, from https://www.statista.com/statistics/1330879/cumulative-number-of-esim-device-shipments-worldwide/

93 Statista. (September 13, 2022). Industries that mobile network operators and device manufacturers believe will account for the greatest share of eSIMs worldwide as of 2021 [Graph]. In Statista. Retrieved December 19, 2022, from https://www.statista.com/statistics/1330842/leading-esim-industry-projected-by-telecoms-business/

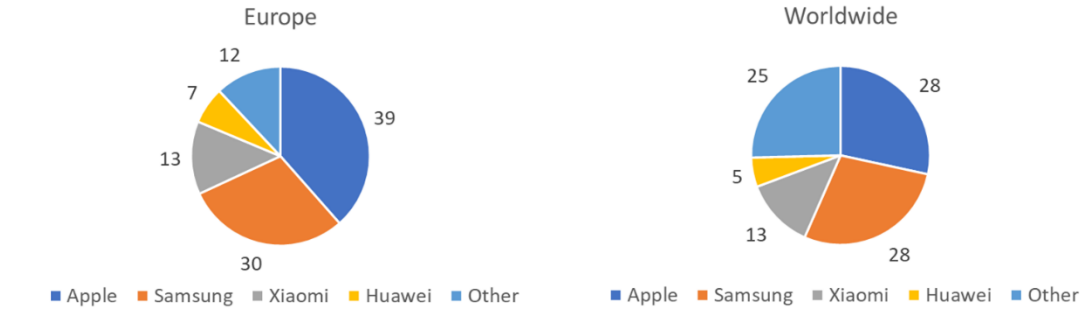
and anticipates that by 2025[94] there will be 2.4 billion eSIM smartphone connections (installed base) which would represent 33% of smartphone connections.

Figure 3-5: Smartphones with eSIM capability

Source: WIK based on Pablo Iacopino (2022).95

As shown in the following figure, eSIM-enabled smartphones in Europe are currently provided predominantly by Apple and Samsung.[96]

Figure 3-6: Smartphone usage by manufacturer in Europe and Worldwide in percent (October 2022)



Source: WIK based on Statcounter 2022.97

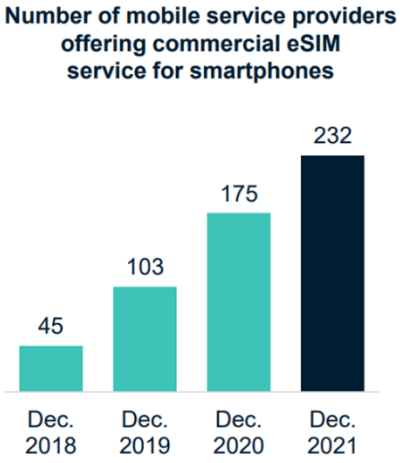
In the USA, Apple's iPhone 14, which was launched in September, is now only available with eSIM, although in Europe, the physical card slot still remains in parallel to the eSIM (for now). According to reports, beta versions of Android 13 will provide software-based "multiple-enabled profiles" for the simultaneous use of several eSIM profiles on one eSIM.

94 See GSMA Intelligence (2021)
95 See Iacopino, P. (2022)
96 See Iacopino, P. (2022)
97 Web Analytics Service, see worldwide: https://gs.statcounter.com/vendor-market-share/mobile/worldwide/2021 (last accessed on 30.11.2022), Europe: https://gs.statcounter.com/vendor-market-share/mobile/europe/2021 (last accessed on 30.11.2022).

It is possible that this will also be possible for devices that receive the corresponding version of Android 13 via an update, i.e. that are not already delivered with it. As far as is known, the second active eSIM profile would substitute for the function of the physical SIM card, i.e. it would not allow three simultaneously active SIMs.[98] According to media reports, Google's new Pixel 7 and Pixel 7 Pro smartphones will provide a similar update and thus offer "multiple-enabled profiles" from March 2023. This would make it possible to activate two eSIM profiles at the same time and to switch between the profiles without switching one of them off.[99] This should enable customers to use multiple connectivity services simultaneously, which today is possible only when using dual SIM devices equipped with a physical SIM alongside the eSIM or multiple eSIMs.[100]

Looking at eSIM service support, by the end of 2021 eSIM services were commercially available from 232 mobile services providers. The GSMA reports that 88% of operators plan to offer eSIM service by 2023 and 98% by 2025.[101]

Figure 3-7: Number of mobile service providers offering commercial eSIM service for smartphones



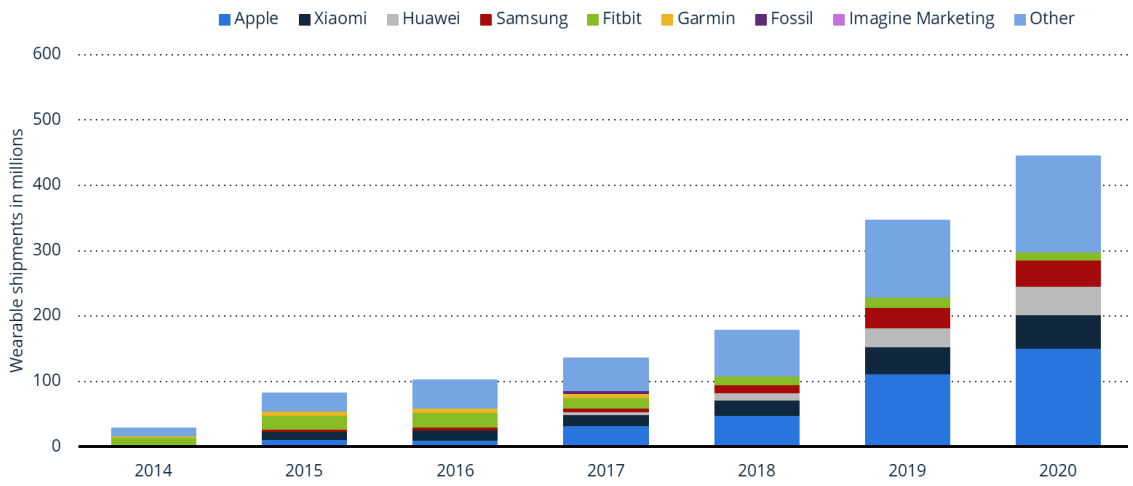
Source: See Iacopino, P. (2022).102

98 See https://source.android.com/docs/core/connect/esim-overview (last accessed on 30.11.2022).
99 See Reinhardt, A. (2022): Pixel 7: Dual eSIM-Support kommt im März 2023, https://www.teltarif.de/dual-esim-pixel-7-pro-maerz-2023-update/news/89630.html (last accessed on 03.11.2022).
100 For example, Apple notes that "You can use Dual SIM by using a physical SIM and an eSIM. iPhone 13 models and later also support two active eSIMs. iPhone models without a physical SIM tray support two active eSIMs." https://support.apple.com/en-us/HT209044.
101 See Iacopino, P. (2022), eSIM in 2022 and beyond: assessing new developments, market trends and consumer behaviour, eSIM Summit at MWC22, https://www.gsma.com/esim/wp-content/uploads/2021/11/MWC22-eSIM-Summit-Main-Presentation-GSMAi.pdf (last accessed on 19.12.2022).
102 See Iacopino, P. (2022), eSIM in 2022 and beyond: assessing new developments, market trends and consumer behaviour, eSIM Summit at MWC22, https://www.gsma.com/esim/wp-

The expansion in eSIM support by MNOs is likely in part due to pressure from the design of modern devices, and the prospect that high end devices may soon be launched without physical SIM cards. At the same time, eSIM activation processes are becoming increasingly user-friendly as eSIM solution providers such as G+D develop fully digitalised onboarding processes. Established mobile providers still rely on QR codes to activate the eSIM, which are scanned by the end customer to set up the mobile provider's profile on their end device.

Most major MNOs in Europe also now offer eSIM support for secondary devices such as smartwatches.[103] The most common eSIM smartwatch models are produced by the smartphone manufacturers Apple (Apple Watch series), Samsung (Galaxy Watch series) and Huawei.

Figure 3-8: Wearables unit shipments worldwide from 2014 to 2021 (in millions), by vendor

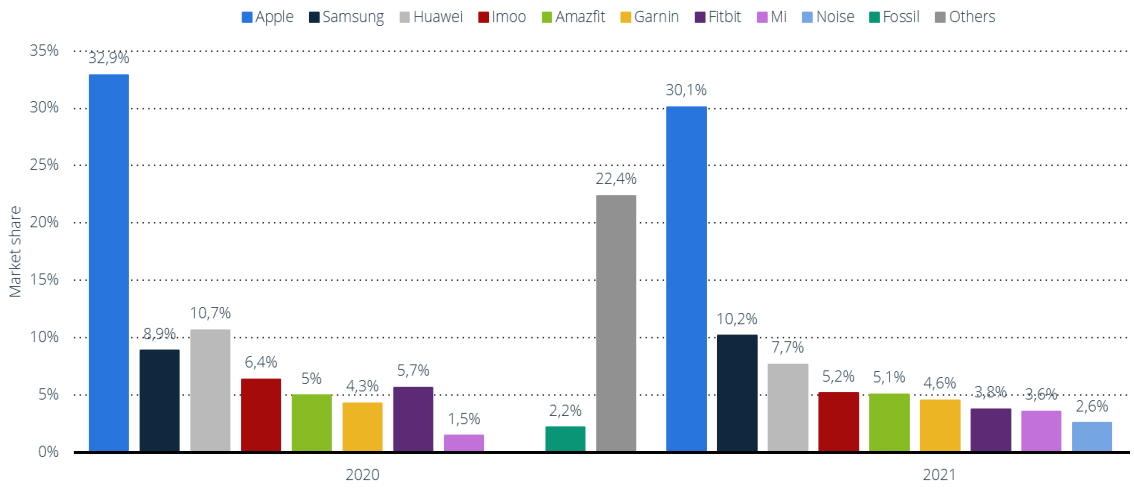


Source: https://www.statista.com/study/36038/smartwatches-statista-dossier/

content/uploads/2021/11/MWC22-eSIM-Summit-Main-Presentation-GSMAi.pdf (last accessed on 19.12.2022).

103 6 out of 8 MNO respondents to the WIK survey conducted for this study (Nov 2022) confirmed that they currently offer eSIM for secondary devices.

Figure 3-9: Smartwatch market share worldwide in 2020 and 2021, by vendor



Source: Telecoms.com (March 14, 2022). Smartwatch market share worldwide in 2020 and 2021, by vendor. In Statista, https://www.statista.com/statistics/1296818/smartwatch-market-share/ (last accessed on 19.12.2022).

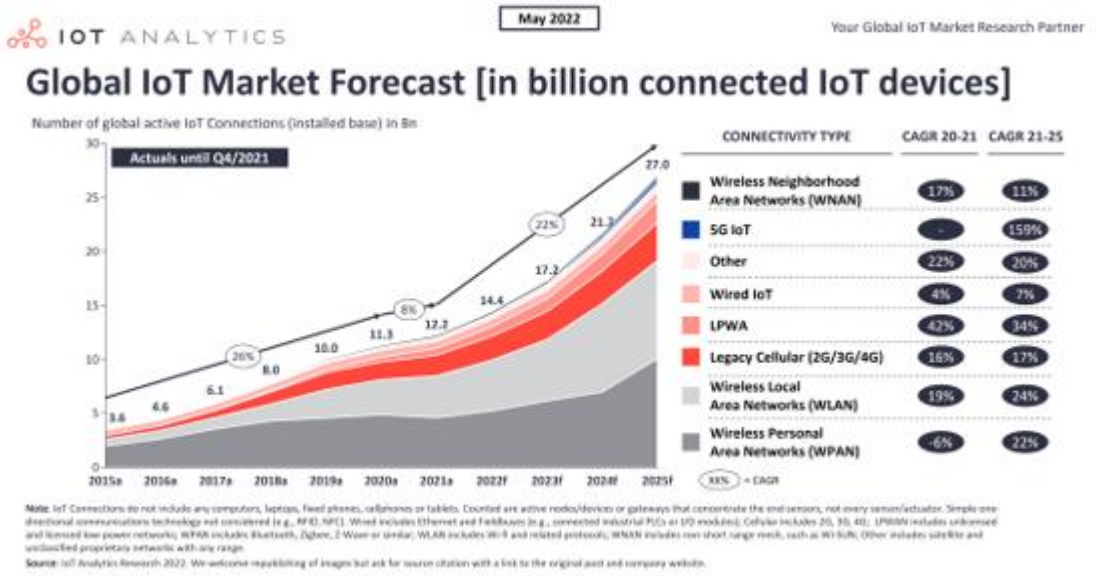
However, this market segment is still relatively limited. Even for Apple and Samsung, only a small proportion of smartwatches are sold as eSIM models and of these, only a small proportion is equipped and activated with an eSIM profile, which in most cases is presumably due to the fact that users are reluctant to incur the ongoing monthly costs to support independent connectivity for their watch.[104]

More generally, eSIM offers significant potential to support mobile IoT connectivity beyond consumer secondary devices. According to the GSMA, there were 1.9 billion IoT licensed cellular connections in 2020 and they will increase to 5.3 billion in 2030.[105] However, although the addressable market for eSIM is considered to be significant, cellular networks (as opposed to non-cellular connectivity) play a minor role for current IoT deployments today (see Figure 3-10) and the connected IoT devices using cellular networks also include (soldered) physical SIM cards.

104 See GSMA Intelligence (2021)

105 See Iacopino, P. (2022), eSIM in 2022 and beyond: assessing new developments, market trends and consumer behaviour, eSIM Summit at MWC22, https://www.gsma.com/esim/wp-content/uploads/2021/11/MWC22-eSIM-Summit-Main-Presentation-GSMAi.pdf (last accessed on 19.12.2022).

Figure 3-10: Global IoT Market Forecast in billion connected IoT devices



Source: https://iot-analytics.com/number-connected-iot-devices/

One reason for the limited use of eSIM in IoT (with the exception of the connected car) may be because early implementations of eSIM-based IoT solutions often rely on proprietary solutions which result in switching barriers. The long lifetime of IoT devices, also means that considerable time may pass before current IoT devices are replaced with eSIM-enabled successors. Another reason may be the lack of an OEM eSIM champion (in contrast with the consumer segment, where equipment manufacturers such as Apple have played this role).[106]

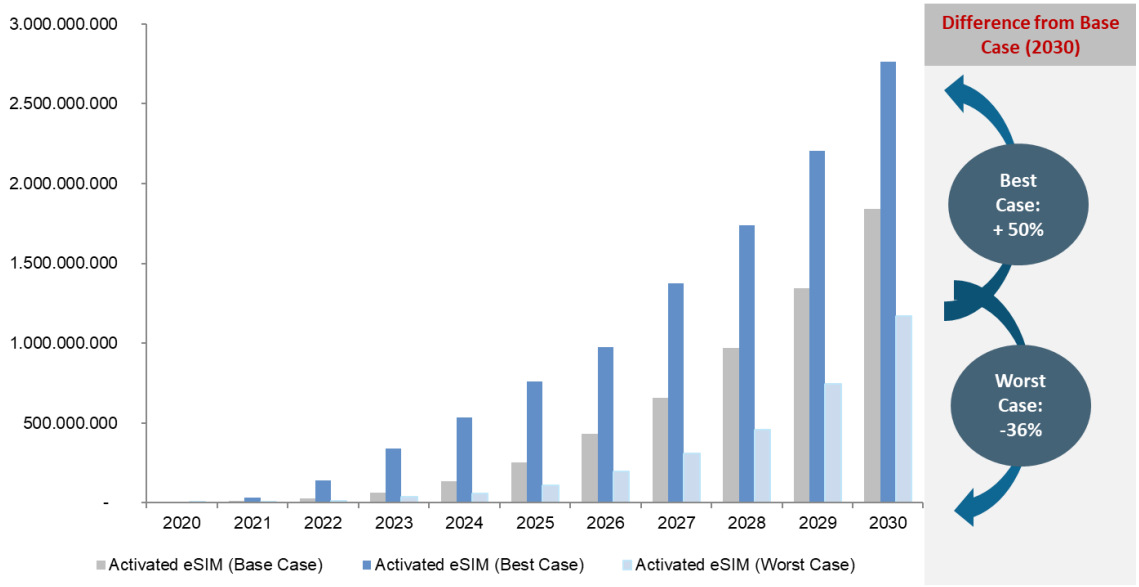
Notwithstanding these barriers, in a 2021 study[107] WIK projected that by 2030, around 2bln eSIM-enabled devices[108] could be active within the EU.

106 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf.

107 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf.

108 The iSIM still is at an early stage of development, but is expected, alongside eSIM, to drive the rapid expansion of the IoT industry in the coming years.

Figure 3-11: Total number activated eSIM in the EU, different scenarios (2020-2030)



Source: WIK-Consult.109

109 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf.

4 Implications of emerging technologies for the value chain

In this chapter, we consider how new technologies may impact the mobile value chain and what might be the implications for the different players in the evolving ecosystem.

- 5G and eSIM could support the development of or improvements in industrial applications in a range of sectors from automotive, through to manufacturing and smart cities. It could also support human to machine interactions such as remote monitoring and healthcare. 5G should enable customers to experience applications using support AR and VR, as well as video conferencing reliably over a mobile connection, while eSIM will enable the development of secondary service providers e.g. for travel.
- As the range of applications expands, the value chain for mobile communications will evolve. Equipment manufacturers, operating system and app providers and "verticals" themselves are likely to play a greater role, alongside specialist MVNOs which target use cases such as Global IoT or travel.
- Technological developments will provide opportunities for players across the value chain to expand into neighbouring areas and/or collaborate with others to provide services. However, it could also be associated with restrictions on competition at the network level, due to increased investment needs for 5G, and at the service level due to lags in renegotiating and updating wholesale access (MVNO and/or roaming) and interconnection contracts to reflect requirements linked to the new technologies.
- In addition, new challenges and bottlenecks could emerge from the control that can be exercised by OEM/OS providers over the eSIM and access to functionalities or support needed to provide services such as 5G or support for secondary devices such as smartwatches. This could be particularly problematic if exercised by platforms with "gatekeeper" power. Consumer MVNOs and smaller MNOs without countervailing buyer power could be at most risk from such practices, although specialist IoT MVNO could benefit if they enter into agreements with OEMs/OS providers.

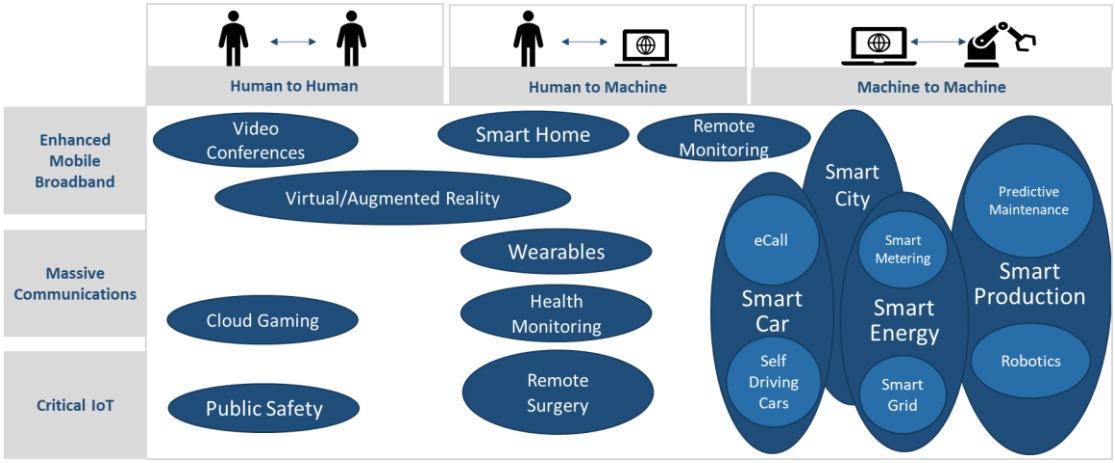
4.1 Service opportunities and players in the evolving mobile value chain

From a basis of offering only the integrated applications of calls and messaging, the mobile value chain has expanded significantly over the last 15 years and a wide range of services and applications can now be delivered over mobile networks. Some of these services are consumer-oriented services that were already available via fixed Internet connectivity or other channels (such as broadcasting), but can now be offered over mobile due to the additional bandwidth capabilities. Other services include new applications that

are targeted at enterprise customers and make use of enhanced quality of service capabilities.

For example, 5G technology could enable existing services such as AR/VR that were offered predominantly over fixed connectivity to be applied to a wider range of mobile use cases such as tourism and retail.[110] Meanwhile, IoT use cases such as smart production, smart energy, smart city and smart car can significantly benefit from 5G capabilities which support applications that need ultra-reliable and real-time connectivity (see sections 3.1.3 and 4.2.3). In addition to the IoT segment other services enabled by 5G include human interaction (e.g. remote surgery) or refer to personal communication between humans (e.g. public safety).his Some examples are provided in the following diagram.

Figure 4-1: Overview on mobile service opportunities (examples)



Source: WIK-Consult

Although we have highlighted specific services that may require 5G SA capabilities, it should be noted as shown in the following table that there are many other services which will be facilitated by 5G but do not necessarily require 5G technology at all or can be implemented in a 5G Non-Standalone scenario.

110 See e.g. OFCOM (2022): Ofcom's future approach to mobile markets, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf , page 37.

Figure 4-2: Illustrative summary of use cases for 5G mobile technology

Technology	Typical use case (subject to demands on capacity)
5G standalone (mid frequency 1GHz-24 GHz, high frequency above 24 GHz)	▪ Fastest connection speed ▪ Highest capacity ▪ Potential for ultra-low latency applications (cloud gaming, immersive media, vehicles or robotic control) ▪ Network slicing, use cases across verticals
5G non-standalone (mid frequency 1GHz-24GHz)	▪ Capacity to support more people undertaking high data rate services (such as higher volumes of demanding 4K video users)
5G non-standalone (low frequency, up to 1 GHz)	▪ General web browsing, social media, gaming, video streaming

Source: WIK based on OFCOM[111], Ericsson[112]

As regards eSIM, new business opportunities derive from the potential to enable mobile connectivity in a wider range of devices including small IoT devices, improvements to the provisioning and switching process and the potential to make use of multiple service profiles.[113]

Specifically, the potential for eSIM to support a fully digitized customer journey makes switching substantially easier for customers, which can foster choice and enable enterprises with a large fleet of devices to manage connectivity remotely.

Due to its capability to support different profiles, eSIM allows the installation of multiple subscriptions on a single device. This can support applications such as using separate subscriptions for personal and business use, additional subscriptions specifically for travel (avoiding roaming charges) or to avoid higher off-net call charges (typically no longer an issue in the EU due to low mobile termination rates, but relevant in some other

111 See OFCOM (2022): Ofcom's future approach to mobile markets, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf, page 42.

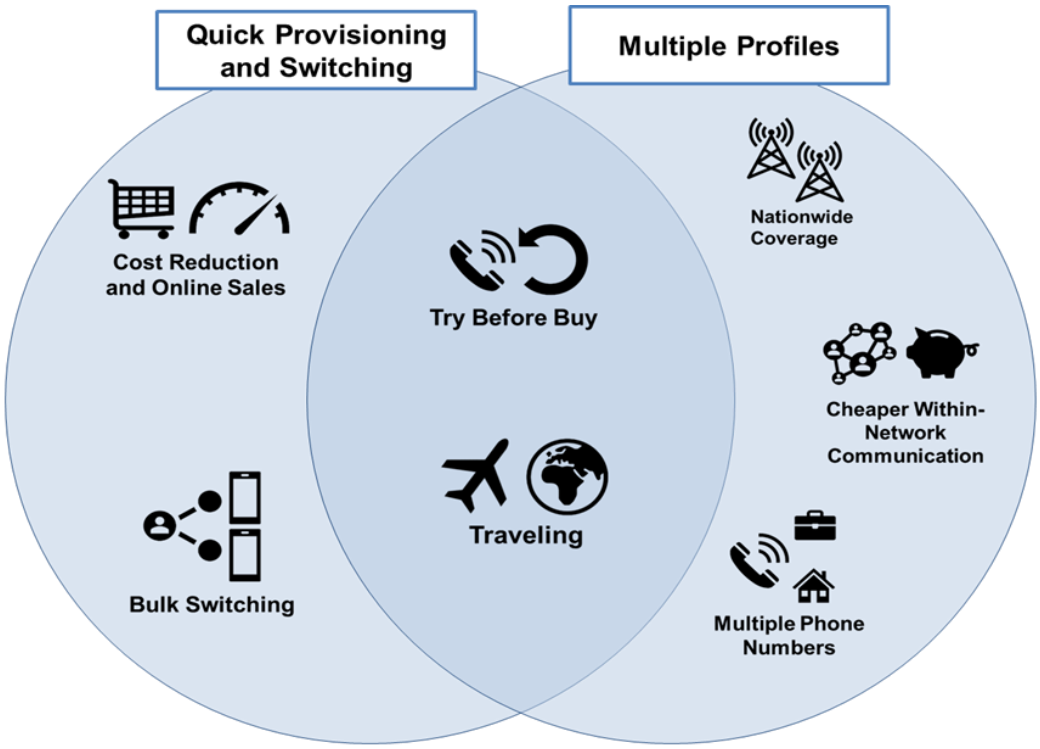
112 Ericsson: 5G standalone, https://www.ericsson.com/en/ran/5g-sa?gclid=EAIaIQobChMIxt7Vz5P5_AIVj713Ch1DfA4AEAAYASAAEgLgN_D_BwE&gclsrc=aw.ds

113 See for the following in detail Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf, page 75-80.

jurisdictions). Multiple subscriptions could also be used to provide back-up and ensure coverage in areas which may be less well served by certain MNOs..

One application that makes use of both the capabilities to support multiple profiles and support switching could be to offer a mobile service for a free trial period to enable “try before you buy”.

Figure 4-3: Applications enabled by eSIM



Source: WIK Consult

Overall, the potential expansion in mobile connected devices and services enabled by 5G and eSIM has the potential to increase the total revenues that could be available across the mobile ecosystem. Some studies predict significant effects. For example, IHS (2019) predicts that 5G will increase revenues to USD 13.2 trillion globally by 2035, if there is a favourable regulatory environment and ongoing progress in standardisation and industry adoption.[114] Most respondents to the survey conducted for this study as well as interview partners agree that the opportunities available from the enterprise and IoT

114 See IHS Markit (2019): The 5G Economy – How 5G will contribute to the global economy, November 2019, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/the_ihs_5g_economy_-_2019.pdf , page 20 (including details on the methodologies applied to the forecast).

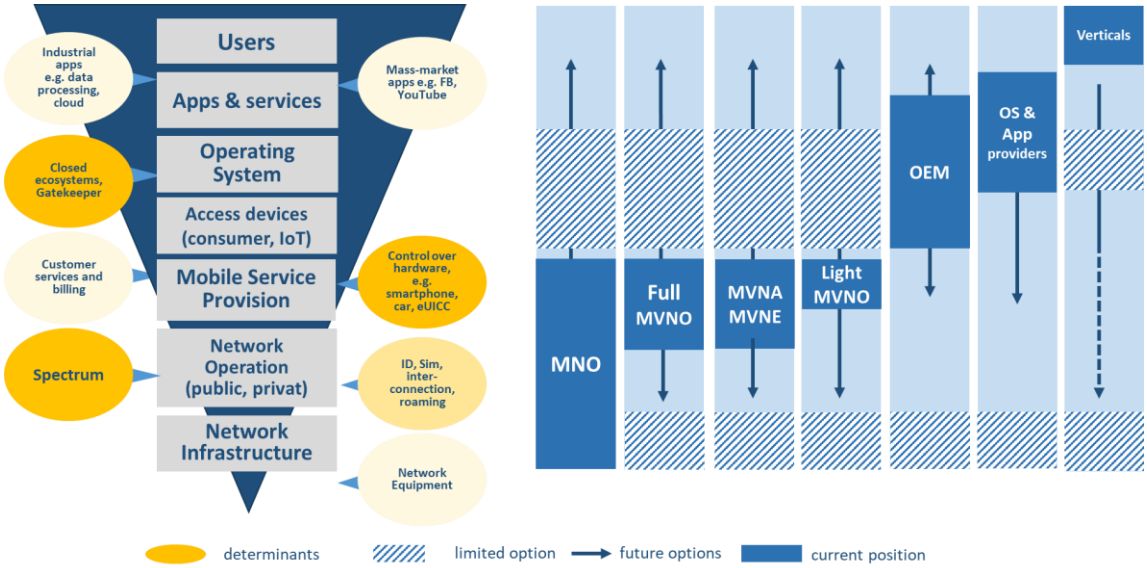
segment could be significant, with a number of MNOs, MVNOs and verticals suggesting that IoT could contribute to a revenue expansion of 60% or more, although others consider that the impact will be more limited.[115] However, most also consider that additional revenue opportunities from personal communications are likely to be limited.[116]

While revenue opportunities for new services are set to expand, there is also a wider set of commercial stakeholders that could play a role in service development. In addition to traditional MNOs and MVNOs, MVNA and MVNE, hardware manufacturers (for both consumer devices and IoT), Operating System, application providers and businesses themselves (so-called verticals) could all tap into this expanding ecosystem, and could seek to provide innovative services and extract value not only within their core field of expertise, but also in adjacent market segments. This means that the value that will be captured in practice by traditional MNOs remains uncertain.

Figure 4-4 provides an overview of the different players that could have a role in the evolving mobile ecosystem, their position in the value chain today and the potential they may have to expand into neighbouring market segments. One common theme is that new technologies provide an opportunity for actors that were not previously present in the mobile sector to move into mobile service provision. However, other levels of the value chain – in particular control at the operating system layer and control over spectrum, will continue to provide limitations for players that are not incumbents in these areas. Further analysis on the factors influencing opportunities and the interaction between players is provided in section 4.3.

115 Source: Stakeholder responses to WIK survey November 2022.
116 This is particularly the case for MNOs. However, some MVNOs responding to the survey predict that 5G could increase (total market) revenues for personal communications by 60% or more.

Figure 4-4: Main players in the evolving mobile value chain



Source: WIK-Consult

In the following sections, we discuss the position in the value chain of each of the main categories of market player in turn and assess the opportunities available to them and the challenges that they may face in achieving their goals. It should be noted in this context that while opportunities are at least in theory open to various types of players, all services require a baseline of connectivity, and some require connectivity meeting specific quality parameters. Thus, the availability of wholesale or self-provided mobile connectivity is a prerequisite for any player which wishes to directly offer services to customers in this evolving value chain. However, connectivity alone is not sufficient to build a presence across the mobile value chain, and other elements may also create tensions or present bottlenecks for certain players. For example, MNOs or MVNOs may be impeded from accessing customers and offering services, if hardware manufacturers and/or those in control of operating systems control the presentation of connectivity operations or restrict access to key functionality. Secondary service providers would be impeded from offering services in eSIM only devices if technical standards continue to limit the potential for profiles associated with connectivity provision to be operated simultaneously.

4.2 Implications for different players

4.2.1 MNOs

MNOs are vertically integrated players operating a broad service portfolio addressed to consumer and business customers. Key strengths for this segment are that they hold spectrum assets and have a long-standing experience in operating networks based on various technologies and are able to provide high coverage and significant data capacity based on a mix of technologies.[117] This means that they have full control over their infrastructure and a high degree of flexibility through which they can provide both basic and more tailored services to their customer-base. Moreover, they have built strong direct relationships with residential and business customers based on a strong brand and diversified distribution channels.

As regards opportunities, MNOs have the option to expand into a wider range of services, beyond so-called "core" mobile services.[118]

Perhaps the biggest opportunity comes from the potential for MNOs to leverage their existing assets - mainly network capabilities and customer relationships[119] – to exploit new IoT revenue potential and develop tailored services and networks for verticals. In this context, a key advantage is that MNOs can offer continuity between public and private networks, which is essential for some industrial use cases which require widespread coverage, but is not readily accessible to other players in the value chain. This means that even when they have access to their own spectrum, verticals may need to collaborate with MNOs to achieve widespread coverage beyond their campus network. Due to the complexities involved in operating networks, many verticals with their own spectrum may also conclude that they are better served by enabling MNOs to utilise this spectrum. Lufthansa, for example, decided in 2020 to deploy a standalone private network in cooperation with Vodafone after a trial phase.[120]

117 See GSMA (2021b): Mobile Networks for Industry Verticals: Spectrum Best Practice, GSMA Public Policy Position, https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Mobile-Networks-Industry-Verticals.pdf , page 5.

118 See GSMA (2022d): The Mobile Economy 2022, https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/02/280222-The-Mobile-Economy-2022.pdf , page 26.

119 MNOs have well-established relationships with verticals due to long-standing contracts for providing the broad range of telecoms and IT services such as connectivity, cloud services, IT security solutions. The strength of this competitive advantage, however, varies strongly between individual MNOs depending on their respective market position in the business customer segment.

120 See Vodafone (2020): Lufthansa Technik and Vodafone Business have built a standalone private 5G campus network at the 8,500 square meters Lufthansa base at Hamburg Airport Hamburg, 27 February 2020, https://www.vodafone.com/business/news-and-insights/company-news/lufthansa-technik-and-vodafone-business-launch-5g-private-network

The 5G Alliance for Connected Industries and Automation (ACIA), a trade body including members from connectivity providers as well as verticals notes that (potentially as a result of these factors), that most verticals will rely on partners to solutions to meet their needs based on public and/or private networks.[121] Even where spectrum is allocated to verticals therefore, it seems likely that MNOs may still have revenue opportunities from delivering networks and services which make use of this spectrum. All MNOs surveyed in this study noted that they cover all market segments including different IoT segments and private (campus) networks. Current industrial 5G offers by the MNOs interviewed mainly focus around private networks particularly those serving industry/production, automotive and smart city applications. None of the MNOs which provided feedback have deployed network slicing to support these applications on any wide scale (although there are "proof of concept trials"). However, all are "planning" to offer network slicing for industrial use cases, and all consider that demand for QoS tailoring, URLLC etc is either present today or will emerge in the next 2-3 years.

In addition to targeting verticals directly, MNOs could also benefit from wholesaling their 5G assets (spectrum leasing and/or MVNO access) to provide these essential connectivity services to others across the value chain.

Most of the MNOs responding to the WIK-Consult survey reported that they host MVNOs – in some cases multiple MVNOs. MNOs stressed that they have an interest in hosting MVNOs in order to contribute to the utilization and monetization of their network, in particular where contributions from MVNOs would be additive to existing revenues. This is confirmed by feedback from industrial MVNOs which suggests that MNOs which do not have a significant presence in vertical segments have been open to reaching MVNO agreements in that segment. However, research suggests that denying access to (or restricting conditions for) MVNOs can be a profit maximizing strategy in cases where MNOs compete with MVNOs and would risk cannibalization and market disruption if they offer access on attractive terms. For example, in an analysis of the impact of the entry of Free in the French mobile market, Bourreau et al. reach the conclusion that before entry, the incumbent MNOs could collude to suppress low-cost brands and thereby avoid cannibalization of their existing revenues and profits.[122] Thus, in this situation of imperfect competition, the provision of MVNO access was a threat rather than an opportunity.

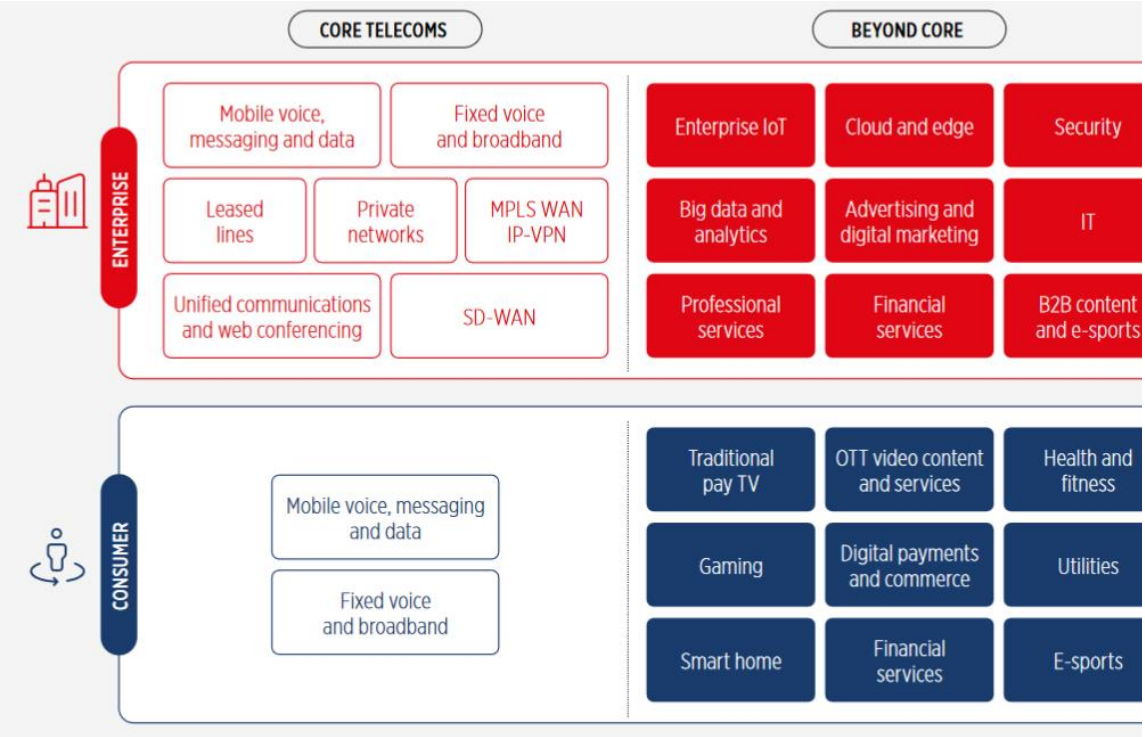
The introduction of eSIM opens up additional opportunities for mobile network operators to develop new networked products that can increase revenue per customer and attract new customers. This includes offering individual contracts for the connectivity of new

121 See e.g. 5G ACIA (2019): 5G Non-Public Networks for Industrial Scenarios, White Paper, July 2019 , https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf , page 5 ff.

122 See Bourreau, M.; Yutec, S. and Verboven, F. (2021): Market Entry, Fighting Brands, and Tacit Collusion: Evidence from the French Mobile Telecommunications Market, in : American Economic Review 2021, 111(11), pp. 3459-3499, https://doi.org/10.1257/aer.20190540 (last accessed on 19.01.2023).

devices, marketing bundled offers with multiple devices that include connectivity for these devices in one contract, and entering or expanding the business with the marketing of usage and user data. It is also important to note that logistics costs associated with distribution of physical SIM cards are not negligible for operators, and thus the rollout of eSIM may be cost-effective, at least in the medium to long term, once parallel operation of the two processes has been phased out.

Figure 4-5: MNO service portfolio



Source: GSMA (2022)123

A key challenge for MNOs has been that they are under pressure to generate new revenues to compensate for significant investments made in 5G spectrum and planned network upgrades.[124] However, they have struggled to monetize the increased demand for mobile data connectivity that has been driven by the evolving app ecosystem. For example, MNOs have not thus far managed to exploit new revenue potential related to

123 See GSMA (2022d): The Mobile Economy 2022, https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/02/280222-The-Mobile-Economy-2022.pdf, page 26.

124 See e.g. OFCOM (2022): Ofcom's future approach to mobile markets and spectrum, Conclusions paper, 6 December 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0036/248769/conclusions-mobile-spectrum-demand-and-markets.pdf, page 18, PWC strategy& (2019): Making 5G pay, https://www.strategyand.pwc.com/gx/en/insights/2019/making-5g-pay/making-5g-pay.pdf (last accessed on 27.03.2023).

content subscriptions for music or news.[125] More generally, MNOs do not see revenue generating opportunities from mass-market 5G, but view it more as a necessity to maintain their existing market position.[126]

Meanwhile as regards industrial 5G, it is uncertain to what extent mobile operators will capture value in relation to other players in the value chain who are involved in the development and provision of industrial applications. In cases where verticals can use their own spectrum, this could limit part of the enterprise market which MNOs might otherwise have targeted, in addition to reducing the portion of 5G spectrum which is available exclusively to MNOs. For example verticals could seek to procure from or engage directly with hyperscale cloud providers, infrastructure companies and/or IT service companies in building private networks.

As MNOs typically operate in national or multi-national (but not global) markets, some also note that they have limited bargaining power compared with global network equipment vendors (e.g. Nokia, Ericsson, Huawei) and strongly depend on a limited number of strong players.[127] One MNO interviewed for this study also cited the ability of key players in the provision of cloud services as limiting their potential to extract value from industrial service provision. The global nature of some industrial applications such as automotive connectivity also creates challenges for smaller MNOs (as well as MVNOs) which cannot leverage their presence in a wider group to negotiate roaming arrangements for global coverage.

Some interview partners also noted what they perceive to be potential threats from regulation which could impede their ability to provide innovative 5G services. One MNO noted that they see the potential that regulation could be applied in relation to their 5G network as a threat to their business case, noting that the substantial investments made warrant the opportunity for them to monetize 5G-based services through their own brands before offering access to others.[128] While not actively welcoming regulation, another MNO was however more sanguine about the requirement to offer MVNOs access to 5G functionality, noting that this obligation was included in their license and had thus been "priced in". Another concern expressed by certain stakeholders is that uncertainties around the interpretation of provisions in the Open Internet Regulation concerning non-discrimination in traffic management could impede their ability to provide innovative

125 See e.g. Deloitte (2022): Future of the UK Mobile and Wider Communications Value Chain. Final Report. February 2022, page 5.

126 Information from interviews and survey with MNOs (Orange, Vodafone, Hutchison Drei Austria and Telia).

127 See e.g. Deloitte (2022): Future of the UK Mobile and Wider Communications Value Chain. Final Report. February 2022, https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/financial-advisory/deloitte-uk-future-of-the-uk-mobile-value-chain-feb-2022.pdf , page 5 and page 12 ff.

128 See also Vodafone (2019): An Industrial 5G Spectrum Policy for Europe, Vodafone Public Policy Paper, https://www.vodafone.com/content/dam/vodcom/files/public-policy/5g-report/an-industrial-5g-spectrum-policy-for-europe.pdf (last accessed on 17.02.2023).

services via 5G network slicing, although the BEREC Guidelines on the OIR note that non-public services (which would likely include many corporate applications of 5G network slicing) are beyond the scope of the Regulation[129] and BEREC has clearly highlighted that network-slicing applications can be introduced in a manner which is compatible with the OIR.[130]

eSIM could also create certain challenges for MNOs. More established MNOs may face the threat of increased competition from rivals as eSIM may facilitate the process of switching both for consumers and IoT as well as potential cannibalization of high value services such as roaming. Hutchison Drei Austria observed that for example international roaming tariffs of MVNOs using eSIM will have a disruptive effect on revenues from connectivity. Moreover, eSIM could affect MNOs relationships with MVNOs, as it could enable MVNOs to switch their host more easily, and without the need for end-users to swap out their SIM card, thereby removing a procedural step which could increase the risk of churn.

MNOs may also lose control over essential functionality that is core to mobile subscriptions, as installation and distribution of the SIM functionality is passed to OEMs. Specifically, the compatibility between the functionalities of the services offered and the operating systems on smartphones and in app stores will play an important role in exploiting the future potential of eSIM. For example, in order to make use of eSIM, mobile operators (MNOs and MVNOs) depend on the Local Profile Assistant (LPA) and the operating system on the smartphone to support the provider profile and the functionalities of the service offered. Some MNOs have expressed concern that OEMs or OS providers could act as gatekeepers, by pre-installing the connectivity provider of their choice or by controlling the ranking of connectivity providers on a choice screen. If a provider is excluded from such a list on equipment which has broad customer appeal, this could significantly affect MNO's potential to gain market share. However, this risk is greater for smaller MNOs and consumer MVNOs. MNOs or global IoT connectivity specialist MVNOs which have the scale or reach to secure a position on such a list may benefit. Some stakeholders have also highlighted concerns that OS providers can exercise control over how equipment and applications interact with network slices on 5G and can leverage this to gain traction in the provision of private networks and network slices.

129 BEREC (2022a): Guidelines on the Implementation of the Open Internet Regulation https://www.berec.europa.eu/en/document-categories/berec/regulatory-best-practices/guidelines/berec-guidelines-on-the-implementation-of-the-open-internet-regulation-0 (last accessed on 27.03.2023).

130 See BEREC (2022b): 5G, https://www.berec.europa.eu/en/open-internet/5g#:~:text=The%20Open%20Internet%20Regulation%20and,by%2Dcase%20basis%20by%20NRAs .

4.2.2 MVNOs

Mobile virtual network operators (MVNO) rely on access to one or more host mobile network operator networks to provide mobile connectivity (and potentially other applications and services) to end-users or other intermediate players in the value chain (such as OEMs / OS providers). Different kinds of MVNOs can be identified, with reference to their target customer groups, technological and operational capabilities.

While some MVNOs focus on providing traditional services (mobile broadband, calls etc) to consumers (either all consumer groups or specific niches), others focus on the delivery of connectivity for secondary devices and/or IoT or address both segments (e.g. Transatel addresses Automotive and Industrial IoT as well as cellular connectivity for end-Use via its brand Ubigi).

From a technological perspective, MVNOs can be distinguished in terms of their degree of operational independence from the MNO (i.e. levels in the value chain in which they operate) and their wholesale pricing model (e.g. whether they have access to data at a price per unit or on a retail minus, revenue share or capacity-basis). These factors have a significant impact on MVNOs options for service differentiation and innovation as well as their commercial flexibility, capital expenses and operational costs. “Branded or licensed resellers” have the least potential for service differentiation compared with their host, while full MVNOs have the greatest capacity for technological or operational innovation.[131] As shown in the following figure, ”light MVNOs” fall somewhere between these two categories.

131 See for a detailed analysis of those business models Godlovitch, I.; Knips, J.; Wernick, C.; Gries, C.; Lucidi, S.; Braun, M. (2021): The role of MVNOs in evolving mobile markets, Study for ComReg (non-confidential), Bad Honnef, September 2021, https://www.comreg.ie/media/2021/10/ComReg-21101a.pdf (last accessed on 27.03.2023).

Figure 4-6: The MVNO ladder of investment

Source: WIK based on Red Dawn Consulting (2019), Nereo (2014), Nereo (2010), PWC (2019) (with modifications).

In addition to their position on the value chain, the impact of 5G and technological developments such as eSIM also depends on the business model pursued by the MVNO (e.g. targeting connectivity for IoT, secondary devices or verticals vs providing mainstream services to consumers), and the strengths they have in other market segments. These aspects are further considered below.

Specialist MVNOs

The capabilities that 5G offers for network slicing provide opportunities for innovation in the fields of IoT and industrial applications for verticals, which could be leveraged by specialized companies relying on MVNO and/or roaming access.

Furthermore the OTA provisioning capabilities of eSIM, are likely to provide significant advantages for multi-national MVNOs to provide connectivity in the IoT segment.

In recent years, MVNOs succeeded in winning important contracts with large automobile manufacturers to provide in-car connectivity (e.g. Truphone with Kia, Cubic with Audi). Players such as Transatel have also increasingly moved into the IoT space. The potential to use a secondary data connection for roaming through eSIM also provides scope for MVNOs to gain more of a foothold in the consumer roaming market. MVNOs such as Truphone and Gigsky have taken advantage of this opportunity.

The main challenges for specialist MVNOs relate to their potential to access the underlying technologies that would permit them to develop quality-assured services on the basis of 5G. While IoT MVNOs report that they have generally been able to reach satisfactory wholesale agreements with at least one MNO in each country, some specialist MVNOs note that the number of available partners is limited due to difficulties engaging with MNOs such as Vodafone, Deutsche Telekom and Telefonica which are part of larger groups which seek to compete in downstream IoT / industrial markets. This can create problems in cases where network resilience is needed, or create wider barriers to entry. For example Germany has been highlighted as a country where access for IoT is challenging because MNOs are themselves active in marketing 5G services to verticals and therefore seek to limit the scope of MVNO access or international roaming they provide to rivals.[132] In this context, Transatel notes that its eSIM-connected Ubigi service which is used in Jaguar and Fiat vehicles is available to all consumers in Europe, except for German consumers travelling in Germany. Transatel also notes that a weakness in specific countries that are considered important in serving global verticals can undermine its potential to compete with large MNOs which benefit from their own connectivity or reciprocal connectivity arrangements with other large groups. More generally, cross-border use cases deployed by MVNOs depend on the treatment of permanent roaming allowances, and these can be subject to restrictions, or conditions which make the IoT business case challenging.

In addition, MVNOs have challenges to make use of NB-IoT for IoT connectivity, in part because NB-IoT is available in a limited number of countries and not supported by all MNOs. This requires MVNOs to engage with several MNOs in order to reach the coverage they often need (at least for cross-border use cases such as fleet management). MVNOs cite challenges in establishing specific roaming agreements for NB-IoT. This is due to not only to the technical complexity involved, but also the reluctance of MNOs to offer access in view of the low revenues per device that can be generated with NB-IoT. It can be observed that NB-IoT roaming has developed slowly and no significant change in dynamics are expected in the years to come. Access to eSIM capabilities is not generally a challenge for this group, as they operate as full MVNOs managing their own eSIM capabilities.

132 See dispute resolution procedures of the Bundesnetzagentur inolving Transatel and MNOs. https://www.bundesnetzagentur.de/DE/Beschlusskammern/1_GZ/BK2-GZ/2021/BK2-21-0005/BK2-21-0005_Antrag.html?nn=997690, https://www.bundesnetzagentur.de/DE/Beschlusskammern/1_GZ/BK2-GZ/2017/BK2-17-0005/BK2-17-0005_Beschluss_download.pdf?__blob=publicationFile&v=2

Consumer MVNOs

Certain types of consumer MVNOs could benefit from the move towards 5G and eSIM. In particular, MVNOs which are focused on data offerings and which could offer seamless digital sign-up could encourage end-users to make use of easier switching opportunities. In this context it is conceivable that well-known consumer app providers could leverage their brand-awareness and expertise in app development to move into the MVNO space. As noted above, eSIM should also provide opportunities for MVNOs to offer secondary services to consumers e.g. data packages for travel.

However, more generally, for retail MVNOs focused on the consumer segment, 5G may rather present a threat than an opportunity as 5G (while essential to maintain market position) is not expected to make significant contributions to revenue[133], but will require new investments (and often renegotiations of existing contracts). Furthermore, MVNOs may not be able to compete effectively against MNOs in 5G-based data offers, if they are not offered 5G access at the same time or under the same conditions as their host.[134] This raises the threat of losing market share, in particular for higher value data intensive contracts.

Among the MVNOs surveyed in this study, most are offering or plan to offer unlimited data. Some report challenges in offering 5G services including challenges negotiating access to 5G, high upfront fees requested by MNOs (5G premium)[135] and/or "pay-per-use" wholesale pricing which makes the high data consumption associated with 5G unprofitable. One MVNO also noted that it faces ongoing uncertainty due to the need to continually renegotiate MVNO access contracts either because they are offered only on a short term basis or because technological or pricing developments need to be reflected.[136]

Along similar lines, MVNOs, may face challenges or delays in obtaining access to VoNR, which could limit the potential for MVNOs to enable innovative features related to this technology and is likely to pose particular problems when legacy technologies are phased out. As evidence of challenges in this area, MVNOs interviewed for this study report that some MNOs do not offer technical support for VoLTE – both domestic and while roaming.

133 For example, Tesco Mobile noted that 5G is necessary to remain in the market, but that they do not expect that they will be able to charge more. At the same time, because data use increases with 5G, costs are expected to increase.
134 Information from interviews with regulators, Ventocom, Tesco Mobile.
135 This challenge was noted by MVNO active in France and the Czech Republic
136 Tesco Mobile notes that contractual arrangements are typically made for a 5-10 year period, but in practice tend to be renegotiated every 3 years to respond to market dynamics.

Moreover, there is a lack of VoLTE compatibility in some cases due to different interpretations of standards in implementation.[137]

The emergence of eSIM may also present a threat to existing larger-scale MVNOs (as well as MNOs) due to the risk of churn, while the proliferation of additional connected consumer devices that is likely to be supported by eSIM may present a further reason for consumers to switch to MNOs. The survey conducted for this study shows that while MNOs are providing connectivity to consumer secondary devices, this is not provided by many consumer MVNOs.

Moreover, many (especially smaller) MVNOs are not able to offer more popular (and eSIM supported) devices or may be restricted from offering certain services over those devices.

One challenge highlighted MVNOs interviewed for this study was that, due to their limited size and bargaining power, they were not able to obtain devices directly from Apple. This has a significant impact on their business case due to the high share of Apple devices within the markets in which they operate

Another challenge was that, even when it was able to obtain devices indirectly, they could not access the carrier profile on the iPhone and it was not possible to support certain features on the device such as personal hotspot, facetime, LTE, Wi-Fi Calling, 5G, eSIM, visual Voicemail[138]. MVNO Europe has also reported that the, lack of technical support for VoLTE from some OEMs/OS providers is a significant problem.

MVNOs also report problems in obtaining the applicable licenses and assistance, which is needed to support Apple's secondary devices such as smartwatches. A key issue in this regard is that secondary devices such as smartwatches require support from entitlement servers. However, there are no industry standards for this function, and some OEMs require proprietary configurations which increases the cost to support certain devices, and may require technical support from the device manufacturer.[139] Apple is again cited by interview partners as posing the most barriers, resulting in limited support for the Apple Watch amongst MVNOs.

137 See MVNO Europe (2022): Response to BoR (22) 143 Draft BEREC Work Programme 2023, 7 November 2022, https://www.berec.europa.eu/system/files/2022-12/BoR%20PC13%20%2822%29%2011.pdf , page 4.

138 See Apple: Wireless carrier support and features for iPhone in Europe, https://support.apple.com/en-us/HT204040

139 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf, page 134. https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf

Consumer MVNOs also have significant concerns that, due to their small scale, they are unlikely to feature on choice lists that could be established by OEMs/OS or be selected as favoured connectivity providers[140] in devices which are sold with default connectivity solutions, which will further limit their potential to build market share.

The move towards all-digital subscription and switching processes could also have a negative impact on consumer MVNOs that have built up their subscriber-base through widespread physical presence such as supermarkets, although this could be mitigated in cases where such players also have a significant online presence (e.g. online groceries).

Another threat to MVNOs affecting both those in the consumer space and IoT MVNOs is that a relatively high proportion of their customer base or supported devices may not be 4G or 5G capable. The switch-off of legacy 2G and 3G technologies therefore presents a significant business risk to some MVNOs that could prompt their users to switch to alternative providers.

The capability to offer eSIM support is on the other hand less of a concern. Most MVNOs surveyed in this study offer or plan to offer eSIM support and to provide their own eSIM solutions rather than relying on solutions provided by their host.

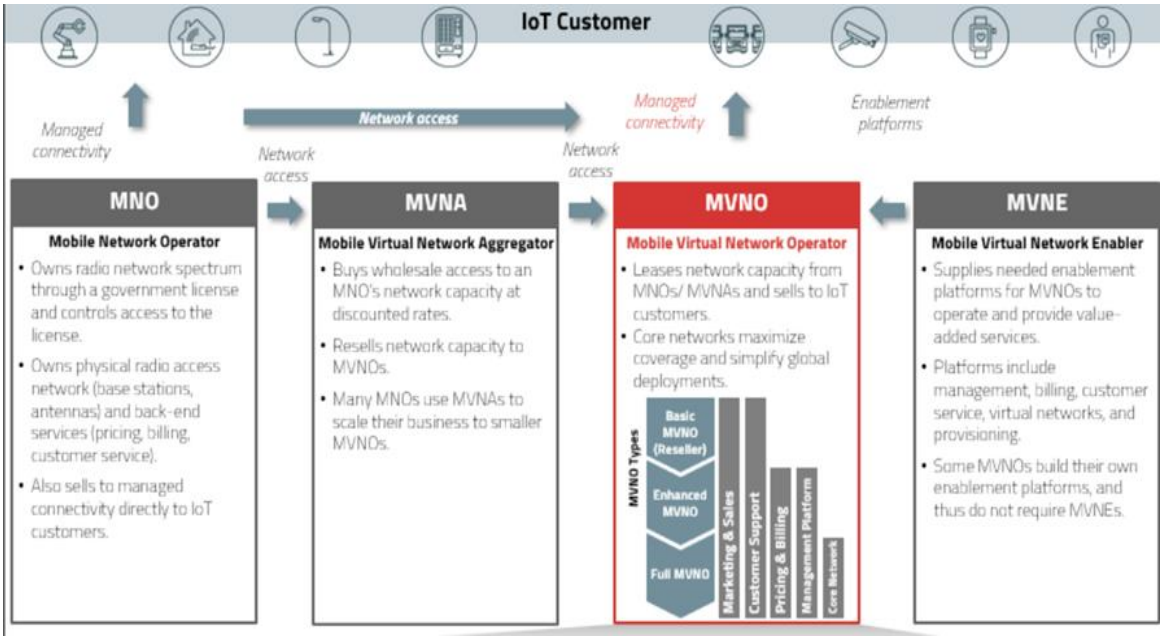
Mobile Virtual Network Aggregators (MVNAs) and Mobile Virtual Network Enablers (MVNE)

The mobile market also provides opportunities for MVNAs (Mobile Virtual Network Aggregators) and MVNEs (Mobile Virtual Network Enablers) that play an intermediate role between MNOs and MVNOs. These types of player can operate independently (and thus as “neutral” providers) or within a structure that also directly provides MVNO services to customers.[141]

140 On the other hand, specialist MVNOs focused on global connectivity may benefit from the ability to reach preferred provider agreements with OEMs (see previous section).

141 See Gray, Ross (2022): What is an MVNO (Mobile Virtual Network Operator)? Sierra Wireless IoT Blog, 19 August 2022, https://www.sierrawireless.com/iot-blog/what-is-mvno/#:~:text=Consider%20those%20roaming%20partners%20to%20be%20Mobile%20Virtual,bundle%20that%20it%20then%20sells%20to%20an%20MVNO (last accessed on 27.03.2023).

Figure 4-7: MVNO, MVNA and MVNE business model



Source: Sierra Wireless[142]

MVNAs establish technological platforms and provide wholesale connectivity. They focus e.g. on providing full coverage based on several mobile networks in a single bundle to an MVNO. MVNAs offer potential attractions in particular to small MVNOs as they can provide access to several MNOs in a single contract. At the same time, they can reduce MNOs' effort to handle numerous requests from small MVNOs.

The relevance of MVNA differs between countries. In France, the cooperation between MVNAs and small MVNOs plays an important role in the market: instead of negotiating directly with the MNOs, MVNOs sign contracts with aggregators such as BTBD (Bouygues Telecom Business Distribution),[143] Transatel and Alphalink. BTBD is reported to have more than 50 MVNO clients.[144]

MVNAs are likely to benefit from a trend towards specialization and from the rise of new players in the IoT segment. All of these companies will need connectivity (often on a global scale), but might be too small to negotiate with all MNOs separately.

142 See Gray, Ross (2022): What is an MVNO (Mobile Virtual Network Operator)? Sierra Wireless IoT Blog, 19 August 2022, https://www.sierrawireless.com/iot-blog/what-is-mvno/#:~:text=Consider%20those%20roaming%20partners%20to%20be%20Mobile%20Virtual,bundle%20that%20it%20then%20sells%20to%20an%20MVNO (last accessed on 27.03.2023).

143 BTBD,is a subsidiary of Bouygues Telecom that expanded into the MVNA business. See Bouyuges, https://www.bouygues.com/en/publications-at-a-glance/magazine/btbd-is-ready-for-take-off/

144 See https://www.btbd.fr/fr/operateurs.html

A major challenge for MVNAs will be to obtain access to multiple MNO networks in order to reach substantial value add in the market, and in this regard they may face similar challenges to those listed in relation to MVNOs, although these challenges might be mitigated by the increased bargaining power that MVNA's may gain from being able to aggregate market share.

MVNEs focus on providing the infrastructure to MVNOs that is needed to provide services as well as associated systems to support services such as billing and customer service. MVNE functions can be provided by MVNA's or independently eRate in Norway, for example, is an MVNE providing platforms and traffic agreements needed to become a mobile operator.[145] eSIM might support the MVNE business model, as they could offer MVNOs assistance in providing the additional infrastructure needed to support remote provisioning and switching.

4.2.3 Verticals

Verticals are "companies, industries and public sector organizations operating in a specific sector".[146] As such, "verticals" includes a wide variety of different types of business end-users. Most verticals have until now relied on electronic communication operators (or IT solutions providers) to provide connectivity, sometimes in a bundle with other applications. Some have deployed (fixed and wireless) private networks to better fulfill their specific connectivity needs. Among verticals' main motivation to deploy private networks are advantages with regard to a better coverage of their facilities (e.g. in remote areas), full and exclusive use of available capacity and control of traffic prioritization, security and other parameters.[147] Current wireless networks rely on different technologies (e.g. WiFi, LTE, LoRaWAN) and support wireless communications and IoT use cases such as asset tracking and remote monitoring. Private wireless networks have been built mainly by large companies so far, e.g. the airport of Amsterdam or Rotterdam port authority.[148] According to Eurostat (2022) large companies, however, represent only 0.2 % of all European enterprises.[149] SME (small and medium sized enterprises) are

145 Information gathered from interviews. See also websites of MVNAs and MVNEs: https://erate.no/ , https://www.transatel.com, https://www.btbd.fr/fr/operateurs.html and https://alphalink.fr/communication/ (last accessed on 19.01.2023).

146 See GSMA (2021): Mobile Networks for Industry Verticals: Spectrum Best Practice, GSMA Public Policy Position, https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Mobile-Networks-Industry-Verticals.pdf , page 2.

147 See e.g. Brown, G. (2017): Private LTE Networks – a Heavy Reading white paper produced for Qualcomm Inc., July 2017, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/private-lte-networks.pdf

148 See for more Reference cases in the Netherlands UlWiMo (Ultimate Wireless Mobility), https://www.ulwimo.com/

149 Definitions: micro and small enterprises (0-49 employees), medium-sized (50-249 employees), large companies (at least 250 employees), see Eurostat (2022): EU small and medium-sized enterprises: an overview, 27 June 2022, https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20220627-1

often referred to as “backbone of the European economy” [150] and play a significant role to drive innovation in Europe. SME mainly consist of very small companies (the share of medium-sized is 0,9%, micro and small enterprises 98,9%)[151] This means that the verticals segment is very heterogeneous and this is reflected in its diverse connectivity and digitalization needs. For SMEs, IoT implementation is a complex process that can be difficult to address with limited resources. While 29% of all EU enterprises used IoT devices in 2021, the share among large companies was 48% compared with 26% for small companies.[152] The SME segment also tends to be less attractive for large vendors/providers due to the relatively small size of each individual project.[153]

Literature suggests that the wide-scale deployment of 5G will play a key role in unlocking opportunities across a wide range of industrial sectors.[154]

Use cases such as fleet and inventory management and tracking, and the deployment of IoT in cities and for agricultural support could play an important role in supporting companies and organizations to optimize their processes, strengthen customer relationships and develop new business models, which should contribute to cost efficiencies and increased productivity as well as new revenue opportunities.

Although some use cases are possible with previous generations of technologies, the use of 5G and eSIM technology is needed in others and could bring additional advantages. In particular certain use-cases which require precision, reliability or very high bandwidths may require 5G SA capabilities, while eSIM is likely to facilitate connectivity for a range of IoT devices, that may not have been able to accommodate a physical SIM. Moreover, eSIM technology significantly reduces the dependency of verticals on mobile network operators. The potential of eSIM to remotely provision connectivity and switch provider has a major impact on the bargaining power of the vertical. Provider lock-in has been a major threat with traditional SIM, as many connected devices deployed by verticals have a long lifetime. The risk of provider lock-in should at least in theory be reduced through the deployment of eSIM, as there will be the potential flexibility to switch the provider during the lifetime of the device.

150 Definitions: micro and small enterprises (0-49 employees), medium-sized (50-249 employees), large companies (at least 250 employees), see Eurostat (2022): EU small and medium-sized enterprises: an overview, 27 June 2022, https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20220627-1

151 Definitions: micro and small enterprises (0-49 employees), medium-sized (50-249 employees), large companies (at least 250 employees), see Eurostat (2022): EU small and medium-sized enterprises: an overview, 27 June 2022, https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20220627-1

152 See Eurostat (2022): Use of Internet of Things in enterprises (2021), May 2022, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Use_of_Internet_of_Things_in_enterprises (last accessed on 27.03.2023).

153 Information gathered in interview with EUWENA.

154 See e.g. World Economic Forum (2020): The Impact of 5G: Creating New Value across Industries and Society, White Paper in collaboration with PwC, January 2020, https://www.pwc.com/gx/en/about-pwc/contribution-to-debate/wef-the-impact-of-fiveg-report.pdf (last accessed on 27.03.2023).

Large Verticals interviewed for this study (such as Bosch and Volvo) report that they have observed an increase in competition, more choice between alternative options and a price decline. A lack of options for connectivity is not identified by verticals as a barrier to their take-up of 5G. They state, however, that the whole ecosystem still needs to develop and for some specific use cases there is a lack of equipment and services as well as a lack of standardization. Therefore, most verticals have not deployed 5G private networks or are still in a trial phase.

For smaller companies, 5G poses even more challenges. Those that are located in business parks are more likely to benefit from 5G campus networks.[155] SME also have challenges which prevent them from taking a decision to implement IoT use cases in general (and provided by public network operators). Among these smaller players, uncertainty is high regarding benefits of 5G use cases in relation to the costs. Therefore, they often tend to postpone their IoT projects and wait for more standardized and less complex solutions.

Although eSIM for IoT shows considerable promise, provisioning is still at a very early phase and it is yet to be seen whether switching will be possible in practice at a reasonable cost as switching operators in the eSIM scenario has not been tested on a large scale in the field. Companies surveyed for this study report that they expect that a change of provider would still require a major effort. This may be due in part to the fact that standards for IoT eSIM lag behind those developed for consumer applications. Specifically, while switching for consumer devices such as smartphones is triggered directly by the end-user, switching of IoT devices must be "pushed" by the organization that controls the system which activates profiles. As this is in many cases the existing connectivity provider,[156] changing connectivity provider would require the industrial customer to continue to use its previous provider for certain functions or a data swap process between the old and new provider. Both scenarios require the collaboration of the connectivity provider whose contract is due to be terminated. Switching is an any event likely to be a project-based process for industrial customers.[157] Other challenges arise in specific situations. For example, Transatel notes that switching connectivity providers for a connected car, involves sending an SMS to the SIM card and the car needs to be switched on in a safe place.

155 See e.g. 5G-Innovationsprojekt – Gefördert vom BMDV – Projektträger VDI/ VDE-IT – Teil der 5x5G Strategie.

156 Industrial customers which maintain control of the SM-SR, which is responsible for the activation of profiles could on the other hand maintain greater control over the switching process.

157 See Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.I.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf, page 82.

On the other hand, verticals which are engaged in manufacturing such as car manufacturers could benefit from the market expansion and revenue opportunities that 5G and eSIM will bring to equipment manufacturers (see below).

4.2.4 Original Equipment Manufacturers (OEM)

With the development of an increasing number of new connected devices, the group of equipment manufacturers in the wider mobile ecosystem is becoming more diverse. While some segments are dominated by global players (e.g. in the smartphone market or automotive market), other segments (e.g. parts of the industrial IoT) are highly fragmented and characterized by a broad range of specialist players. Depending on their business model and market position, there are a variety of market opportunities for OEMs deriving from 5G and eSIM.

The most obvious advantage of eSIM for equipment manufacturers is that SIM card slots are no longer required. This provides greater leeway in the design of devices which is particularly beneficial for the production of smaller end-user devices with connectivity where it was previously not possible to accommodate SIM card slots (e.g. smartwatches, trackers). This also applies to IoT devices that have high demand on robustness an resistance (e.g. trackers in oil tanks). 5G will also support market expansion, as it will enable new use cases including for IoT. As a result, there will be the potential to produce a wider range of connected devices, leading to increasing revenues for equipment manufacturers.

OEMs could also take advantage of the fact that they can control the eSIM installation and deployment of the related interfaces to bundle connectivity or provide interfaces or options for connectivity into their offers. This is already happening in the IoT segment including for consumer secondary devices. For example Microsoft has partnered with Transatel to provide connectivity for certain notebooks.[158] Meanwhile, certain car manufacturers have opted to partner with or invest in MVNOs (such as the minority stake of Audi Electronics Venture in Cubic Telecom in 2015).[159] In an interview for this study, Transatel noted that car manufacturers are squeezed between big MNOs and big OS providers, if they stick to their existing position in the value chain, while the option to become a full MVNOs themselves allows them to regain control over important issues related to economics, services and security. The sale of (or revenue share relating to)

158 See Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, J.S.; Taş, S. (2019): Technological developments and roaming, WIK-Consult report for the European Commission, https://op.europa.eu/en/publication-detail/-/publication/7c74b70b-b4d8-11e9-9d01-01aa75ed71a1, page 65

159 See Europewire (2015): Audi Electronics Venture GmbH acquired strategic stake in global forerunner in M2M technology Cubic Telecom, 6 May 2015 https://news.europawire.eu/audi-electronics-venture-gmbh-acquired-strategic-stake-in-global-forerunner-in-m2m-technology-cubic-telecom-765432123456789/eu-press-release/2015/05/06/17/27/39/34210/ (last accessed on 27.03.2023).

connectivity could provide an important additional revenue stream for OEMs, but also risks an "aftersales" lock-in challenge for consumers, which could be especially pronounced for high value goods.[160]

As consumers are familiar with choosing a connectivity provider for their primary mobile device, it seems less likely that smartphone manufacturers will sell these devices with connectivity pre-installed. However, smartphone manufacturers could leverage their control over the eSIM installation process and associated interfaces to favour specific mobile service providers. They also have the capability to block access to certain hardware features such as 5G. The potential to exercise this capability may particular apply to global players like Apple and Samsung which have a combined share of about 65% of the installed base of smartphones in Europe. However, larger MNOs (but not smaller MNOs or consumer MVNOs) and in particular those which are part of large groups or are present in larger markets may have a degree of market power of their own in negotiations with the global giants due to the high proportion of subscribers that may rely on their MNO to provide handsets.

In the IoT segment, devices can be produced without the need to include connectivity in advance, as the remote provisioning capability allows to have just a bootstrape profile and the connectivity provider is added by the user later according to his connectivity needs.

However, eSIM capability for remote provisioning and switching offers possibilities going far beyond. Based on eSIM technology, smartphone manufacturers could expand into the service provision segment. This potential does both strengthen their customer relationships and their negotiation power towards MNOs/MVNOs. The choice of customers as well as competition could be limited. This move would be most likely for larger players and not the huge number of small smartphone manufacturers.

4.2.5 Mobile operating system providers

The mobile operating systems market is today a de-facto duopoly between Google (Android) and iOS (Apple).[161] Other players such as Samsung Bada, Nokia's Symbian are present, but do not play a significant role in the market today. Entry barriers into the

160 WIK-Consult (2021) Strategies to promote Over-the-air provisioning https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 27.03.2023).

161 See e.g. a Competition and Markets Authority (CMA (2022)): Mobile ecosystems -Market study final report, 10 June 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096277/Mobile_ecosystems_final_report_-_full_draft_-_FINAL__.pdf and OFCOM (2022): Ofcom's future approach to mobile markets A discussion paper, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf , page 53.

mobile OS segment are high, mainly due to indirect network effects and the need to attract a critical mass of users and developers at the same time.[162]

The strategies of the two leading players in mobile OS differ. While Apple's OS is only available on Apple devices, Apple devices have a strong share in the mobile segment, in particular in Europe, where they account for 35% of the market.[163] Google's Android is installed on a wide range of smartphones, but it is a niche player in smartphone manufacturing (Pixel). Apple generates about 80% of its revenues with device sales, Google 90% of its revenues with advertising (in a broader sense).[164] Compared to Apple, Google's ecosystem is more open in some respects (see Figure 4-8). Both, however, have a strong position in relation to online content and application providers, as the App Store (iOS) and Play Store (Android) account for the major amount of downloads (in the UK over 90% of native downloads in the UK in 2020).[165]

The mobile ecosystems of Apple and Google – and in particular their role in relation to other market players and consumers have been analyzed by the UK competition authority CMA,[166] and is illustrated in the following diagram.

162 See WIK Cullen International ICF (2021) Digital Markets Act Impact Assessment support study https://op.europa.eu/en/publication-detail/-/publication/0a9a636a-3e83-11eb-b27b-01aa75ed71a1/language-en (last accessed on 27.03.2023).

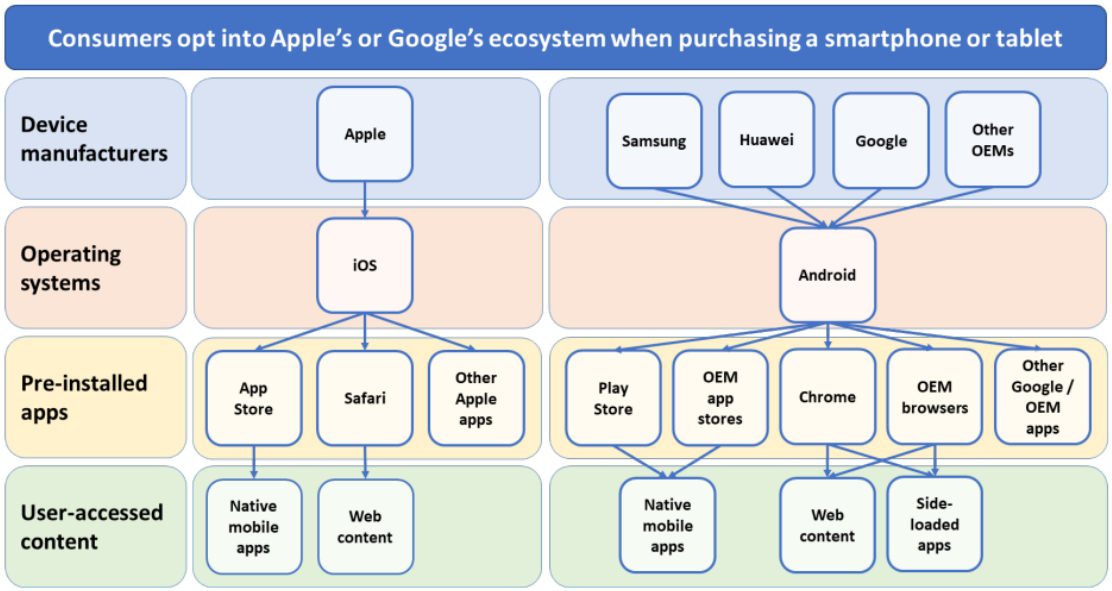
163 According to Statcounter, the worldwide share of Android in mobile OS was 72%, iOS 27% (less than 1% refers to Samsung and unknown OS) at the end of 2022. In Europe, Apple plays a stronger role with 35% market share, GoogleAndroid 65% market share.

164 See Competition and Markets Authority (CMA (2022)): Mobile ecosystems -Market study final report, 10 June 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096277/Mobile_ecosystems_final_report_-_full_draft_-_FINAL__.pdf , S. 9

165 See OFCOM (2022): Ofcom's future approach to mobile markets A discussion paper, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf, page 34.

166 See Competition and Markets Authority (CMA) (2022): Mobile ecosystems -Market study final report, 10 June 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096277/Mobile_ecosystems_final_report_-_full_draft_-_FINAL__.pdf (last accessed on 27.03.2023).

Figure 4-8: Mobile OS providers' ecosystems



Source: Competition and Markets Authority (CMA) (2022)[167]

Although two players dominate the provision of OS for handsets, numerous specific IoT OS are in place to target the needs of the massive numbers of small devices with low-power, such as Windows 10 IoT, Amazon FreeRTOS, Nucleus RTOS by Siemens, Linus-based Tizen. It is conceivable that the proliferation of new devices supported by eSIM and 5G could provide the potential for market entry or enable existing smaller OS providers to expand. Equally however, this development might strengthen the existing ecosystems of the largest mobile OS providers due to network effects.

eSIM could provide an opportunity for OS providers to sell mobile internet access directly to the end user and to bind the customer even more strongly into their own ecosystem, selling them a wider service bundle and increasing ARPUs. Moreover, they could use their OS as platforms on which users choose their mobile subscription provider and this selection could be restricted by them.[168] As discussed in relation to OEMs, this is already occurring in relation to secondary devices and IoT, which are new to the market and may not have had mobile connectivity previously. It is also conceivable that on primary devices (smartphones) mobile operating system providers could take a share of the revenues

167 See Competition and Markets Authority (CMA): Mobile ecosystems -Market study final report, 10 June 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096277/Mobile_ecosystems_final_report_-_full_draft_-_FINAL__.pdf , page 12.

168 See also OFCOM (2022): Ofcom's future approach to mobile markets A discussion paper, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf , page 53.

from connectivity partners and/or from connectivity providers which sell services via their app store.

If the sale of connectivity were to shift increasingly to app stores and revenue shares of app store operators remain high, this could lead to a redistribution of revenues in the value chain. The shift to digital sales channelled through the app store could have a particularly significant impact on traditional consumer MVNOs which have relied on physical outlets to market their services,[169] and may impact some MNOs as well.

It also seems conceivable that operating system providers could enter into the provision of eSIM functionalities or take on the role of eSIM provider, especially in the case of software-based eSIM solutions.[170]

The use of cloud to support IoT applications and the virtualisation of networks which will be accelerated by 5G provides another opportunity for cloud service providers to play a significant role in the provision of electronic communication services. Both Google and Microsoft have substantial cloud capabilities and offer cloud services to their customers. With the increasing importance of cloud services, the importance of cloud providers in the provision of connectivity could increase both in terms of the offer to business customers and for MNOs themselves in managing their network.[171]

4.2.6 Software and application providers

App providers can be distinguished between the large segment of small specialists and a small group of large players.

With eSIM, the connectivity subscription and service management process will increasingly become fully digitally and app-based. Therefore, the existing business model of application and software developers can be extended. The most obvious benefit for them is to provide solutions for customer onboarding that ensure a streamlined customer journey including security, analytics and identification features. These kind of solutions could be offered to other market players. This approach is taken e.g. by Mobilise providing

169 See in more detail Strube Martins, S.; Knips, J.; Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, WIK-Diskussionsbeitrag Nr. 490, Bad Honnef, Dezember 2022, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf , page 21.

170 However, it must be taken into account that eSIM providers have to go through an elaborate certification process. See Strube Martins, S.; Knips, J.; Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, WIK-Diskussionsbeitrag Nr. 490, Bad Honnef, Dezember 2022, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf .

171 See OFCOM (2022): Ofcom's future approach to mobile markets A discussion paper, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf, page 7 and 63.

eSIM as a service that is based on its digital BSS platform HERO and has the German MVNO Freenet as a client.[172]

Moreover, App providers could resell eSIM subscriptions in a mobile App, although the interactions required with OS providers could pose challenges, in particular for smaller app providers and start-ups.[173]

Leading voice, video and messaging application providers such as Facebook (with its WhatsApp service) are likely to continue to play a significant role in offering alternative communication services to those provided by mobile network operators. As such it seems likely that they will incentivise innovation in managed communication services and constrain the ability of mobile network operators to charge excessive prices for these services. As application providers have strong brand recognition, they also have the potential to leverage their brand into provision of connectivity, based on MVNO access. Google provides an example of a major app provider that has experimented with offering its own connectivity services as an MVNO and Wi-Fi aggregator, through Google Fi.[174] The service is still running, but is focused on the US and it seems that it has not been significantly expanded since its launch in 2015. Information about the project – e.g. number of users – is very limited.[175] With purchase of electronic communications going digital, there is a possibility that a similar offer could be made by major app providers in Europe although the perceived need for such a pan-European offer may be limited by the presence of "roam like at home" and app providers have not announced any intention to launch as MVNOs in the EU as of yet.[176]

In the IoT segment, enabled by eSIM and 5G technology, an increased demand for Apps can be expected. Many user cases in the IoT involve interactions between end-users and connected devices (e.g. in relation to predictive maintenance, streamline asset tracking, supply chain monitoring) and require a mobile App. Apps for IoT are becoming more complex, as they need to consider requirements in fields such as data storage, connectivity, IT security, data protection aspects.[177] IoT provides a major opportunity for application developers to produce applications dedicated to specific types of IoT.

172 See https://www.mobiliseglobal.com/

173 See in detail Frid, Albin (2020): eSIM Re-Selling on Mobile App, 29 May 2020, Master's Thesis at the department of electrical and information technology, faculty of engineering, Lund University, https://www.eit.lth.se/sprapport.php?uid=1308 (last accessed on 27.03.2023).

174 See Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, J.S.; Taş, S. (2019): Technological developments and roaming, WIK-Consult report for the European Commission, https://op.europa.eu/en/publication-detail/-/publication/7c74b70b-b4d8-11e9-9d01-01aa75ed71a1, page 69

175 See e.g. Hardesty, L. (2021): Google Fi runs TV ads in 6 local markets, 1 June 2021, https://www.fiercewireless.com/operators/google-fi-runs-tv-ads-6-local-markets (last accessed on 27.03.2023).

176 See Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, J.S.; Taş, S. (2019): Technological developments and roaming, WIK-Consult report for the European Commission, https://op.europa.eu/en/publication-detail/-/publication/7c74b70b-b4d8-11e9-9d01-01aa75ed71a1 , page 70.

177 See e.g. Carrington, Matthew (2023): Mobile IoT: The Impact on the App Development Industry, 20 January 2023, https://www.velvetech.com/blog/iot-mobile-development/ (last accessed on 27.03.2023).

However, a challenge for App providers is their dependency on the App stores operated by Apple and Google that provide the most important (Google Play Store) or even exclusive option to sell Apps to smartphone users. The revenue share taken by those OS providers has a significant impact on the business opportunities of App developers. It is difficult to predict, if and how this situation might change in future.

4.3 Overview of impacts on stakeholders

With regard to the entire mobile communications market, opportunities from 5G and eSIM exist for all stakeholders including the potential to expand revenues and enter adjacent market segments. Opportunities seem to be greatest in the IoT segment. However, equally, there are risks that some actors may not be able to realize these opportunities, while the advent of the eSIM and increasing role played by applications and software could create new bottlenecks in the value chain.

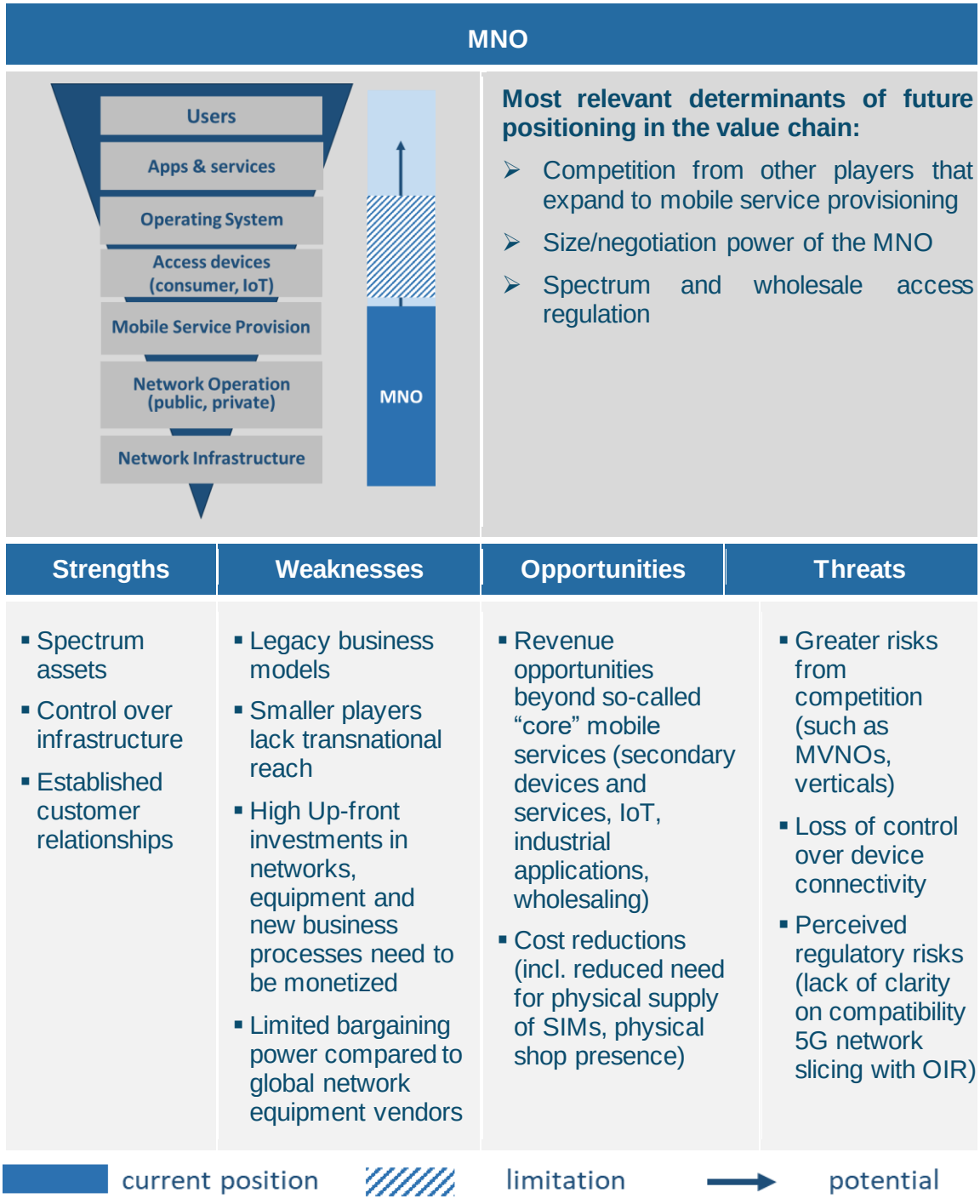
One key aspect of the value chain which may present barriers to expansion for actors looking to engage beyond their traditional remit lies in control over spectrum which restricts the potential to deploy mobile networks and can, where competition is not effective, constrain the potential for non-MNOs to offer mobile services or applications which depend on mobile connectivity. Constraints in this area may take the form of delays in access or terms and conditions which impede the full use of new technologies (for MVNOs). On the other side of the value chain, barriers to expansion may arise from market power which can be exerted by major equipment and OS providers. These barriers may take the form of refusal to supply popular devices, restrictions on accessing the functionality of these devices and/or the potential to restrict the choice of connectivity provider. These effects are particularly strong when exercised by leading players in the consumer OEM and OS segments, and may particularly disadvantage smaller MNOs, MVNOs and application providers which do not have sufficient bargaining power to negotiate attractive conditions. On the other hand, specialist IoT MVNOs could benefit from partnerships with leading OEM and OS providers and leverage their market presence to challenge MNOs, increasing competition in the provision of connectivity. The role of verticals could significantly change in the future, as they become not only a key customer group with increased negotiation power, but potentially suppliers of connected devices and (co)developers of IoT applications. In some cases, verticals may also operate private mobile networks or act as MVNOs.

A SWOT analysis for each stakeholder group is provided in Figure 4-9 to Figure 4-17. In each case we indicate opportunities for different stakeholders to extend their business into other areas of the value chain. This could be done directly in some cases or through partnerships with other players as can be seen in the collaborations between verticals

and MNOs or specialist MVNOs[178] in the deployment of connected solutions, or between verticals and mobile equipment manufacturers to jointly manage the entire value chain in areas where they control spectrum.

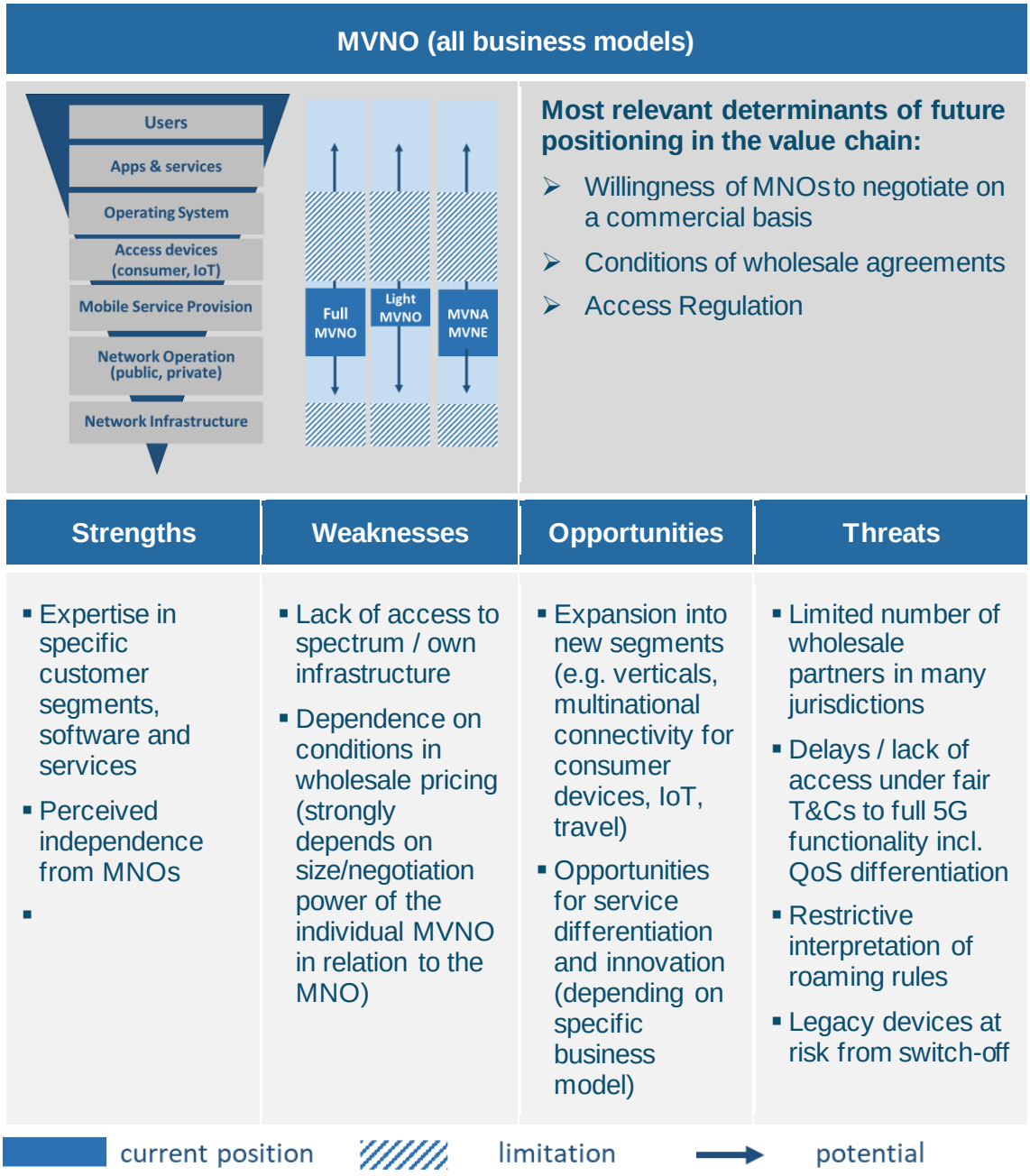
178 An example is the extensive cooperation between Cubic Telecom, a pioneer in connected car founded in 2009 as a global platform provider, and Volkswagen. The cooperation between them was strengthened by a minority stake of Audi Electronics Venture in Cubic Telecom in 2015 (transferred to Volkswagen AG in 2020) .

Figure 4-9: Impact of new technologies on MNO – Summary



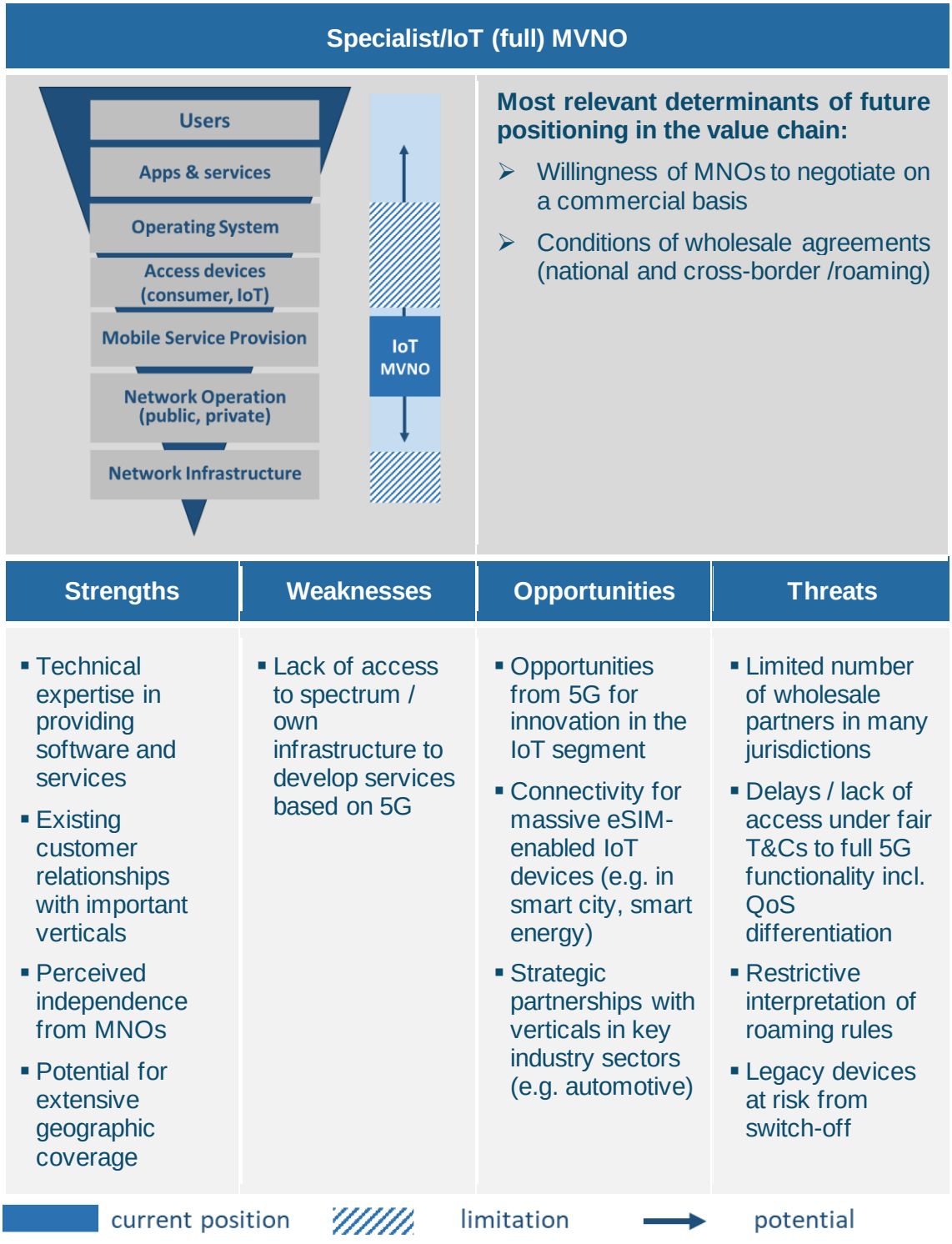
Source: WIK

Figure 4-10: Impact of new technologies on MVNO (all business models) – Summary



Source: WIK

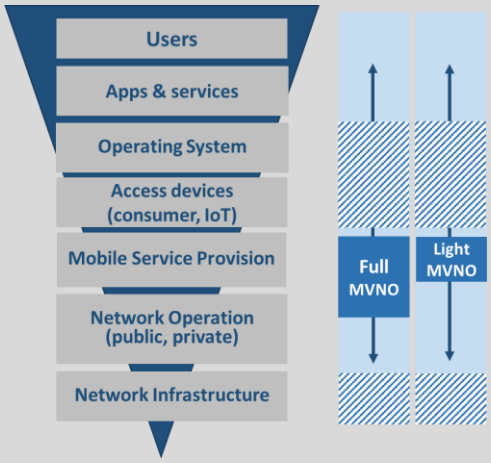
Figure 4-11: Impact of new technologies on Specialist / IoT MVNOs – Summary



Source: WIK

Figure 4-12: Impact of new technologies on Consumer MVNO – Summary

Consumer MVNO



Most relevant determinants of future positioning in the value chain:

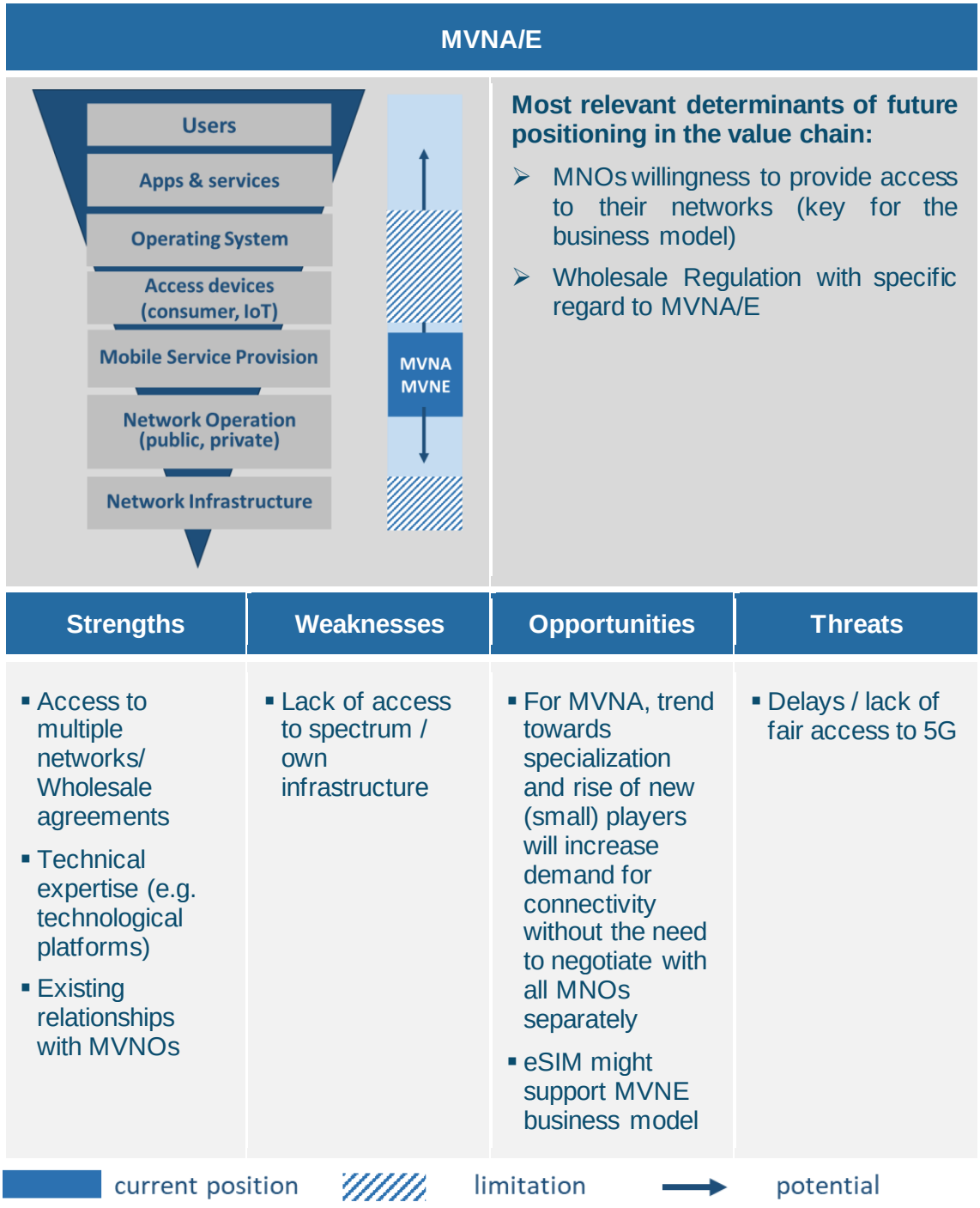
- Willingness of MNOs to negotiate on a commercial basis
- Conditions of wholesale agreements
- Interaction with OEM

Strengths	Weaknesses	Opportunities	Threats
▪ Strong brand / marketing capabilities ▪ Perceived independence from MNOs	▪ Lack of access to spectrum / own infrastructure ▪ Limited investment capabilities compared with MNOs	▪ Potential entry opportunities for companies with strong digital brand recognition ▪ Data offers for secondary devices ▪ Expansion into new segments (e.g. some parts of the IoT)	▪ Delays / lack of fair access to 5G ▪ Digitisation of sign-on (challenge for physical MVNOs) ▪ Restricted access to popular devices and (potential) “provider choice lists” ▪ Lack of support from, OEM/OS providers for all features (e.g. VoLTE) ▪ Legacy devices at risk from switch-off

current position limitation → potential

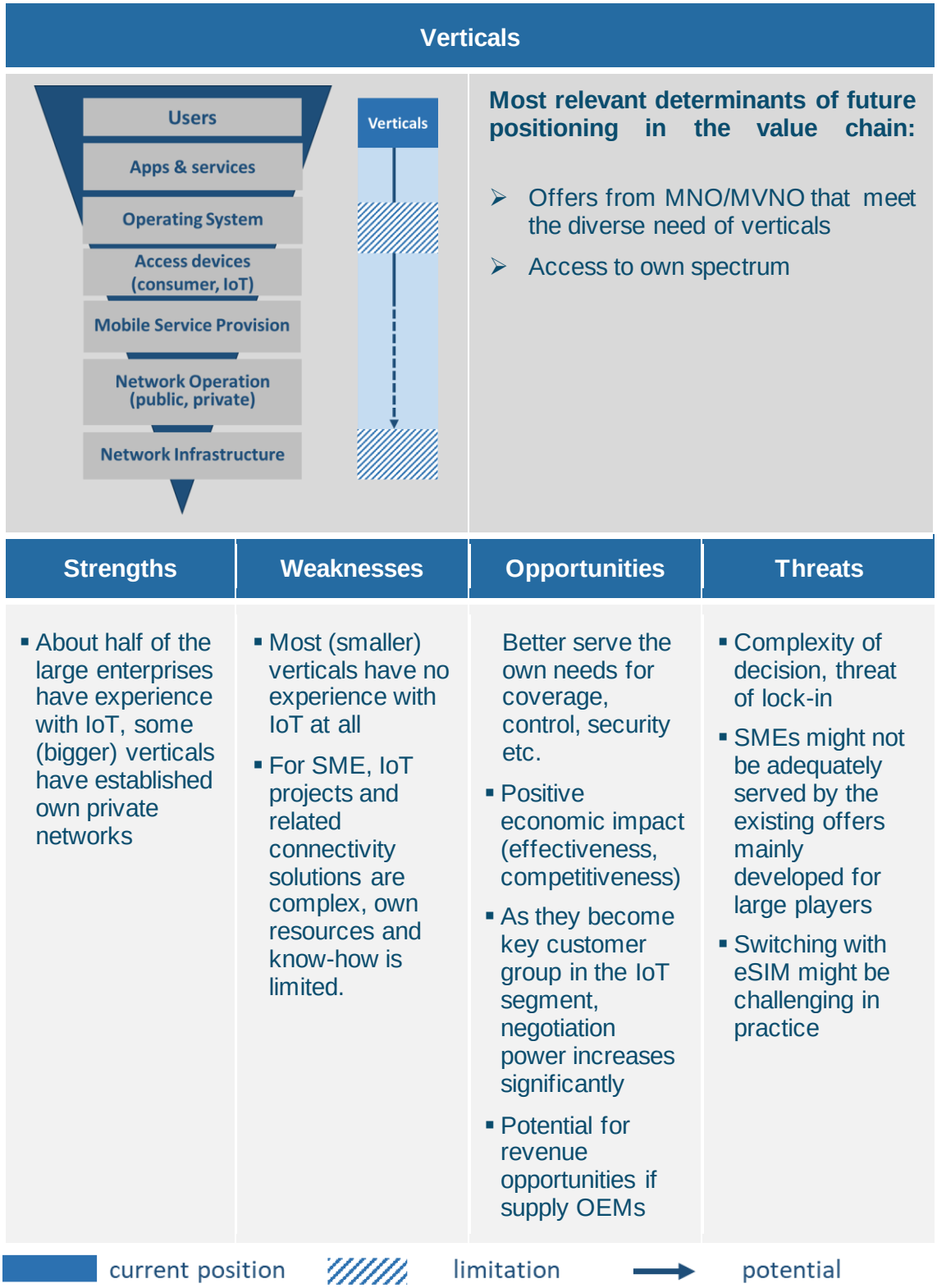
Source: WIK

Figure 4-13: Impact of new technologies on MVNA/E (Intermediaries) – Summary



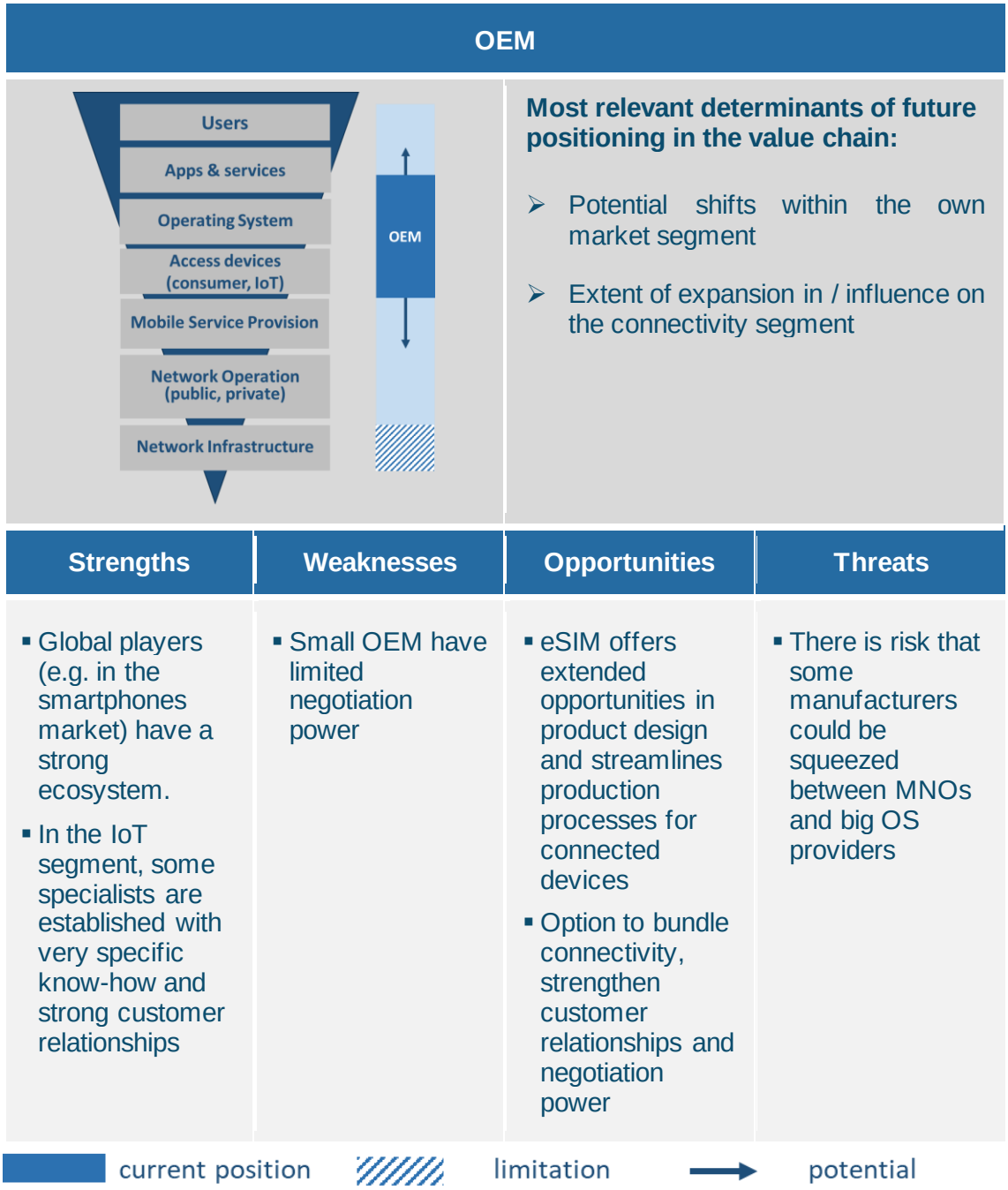
Source: WIK

Figure 4-14: Impact of new technologies on Verticals – Summary



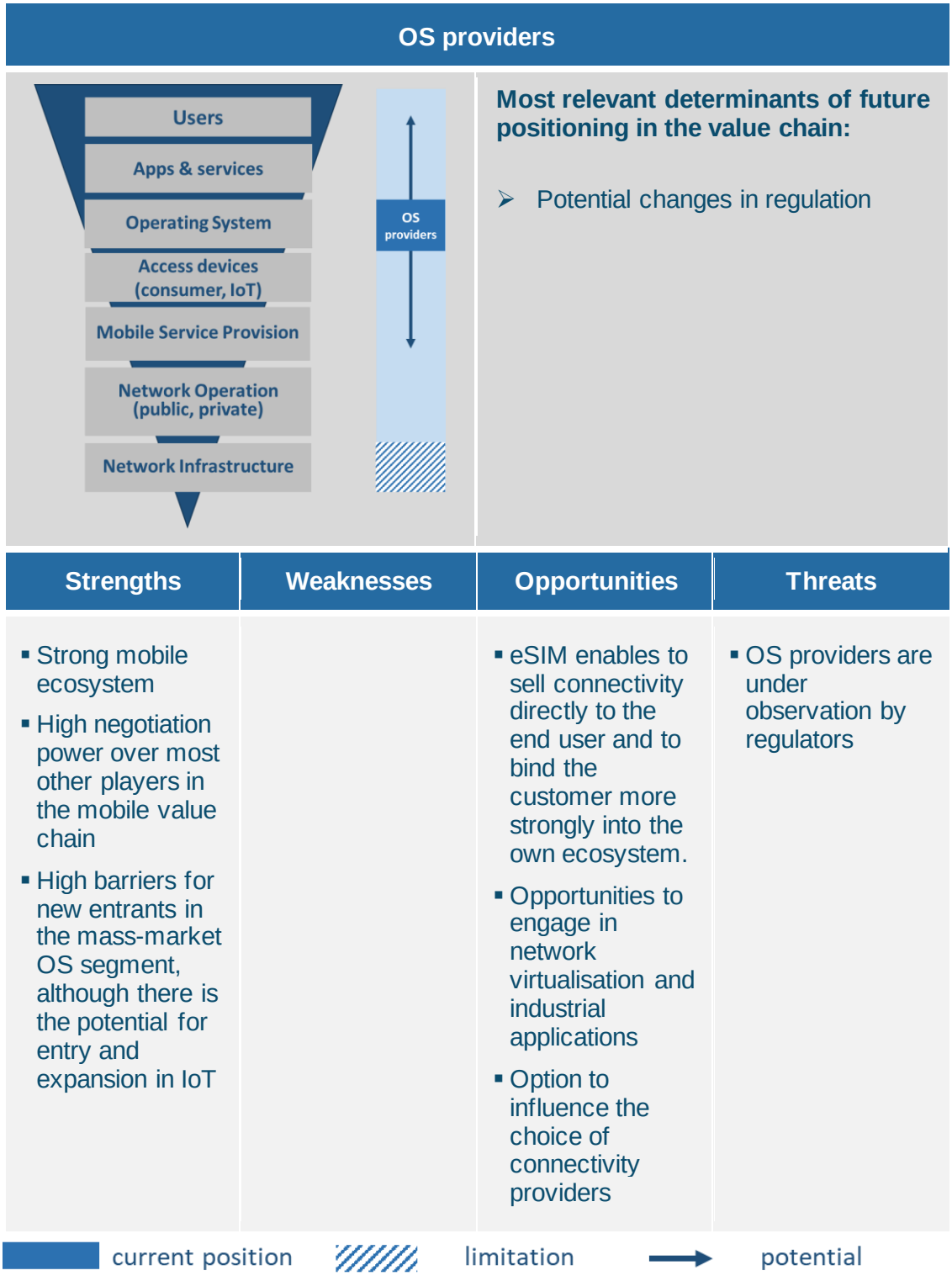
Source: WIK

Figure 4-15: Impact of new technologies on OEM – Summary



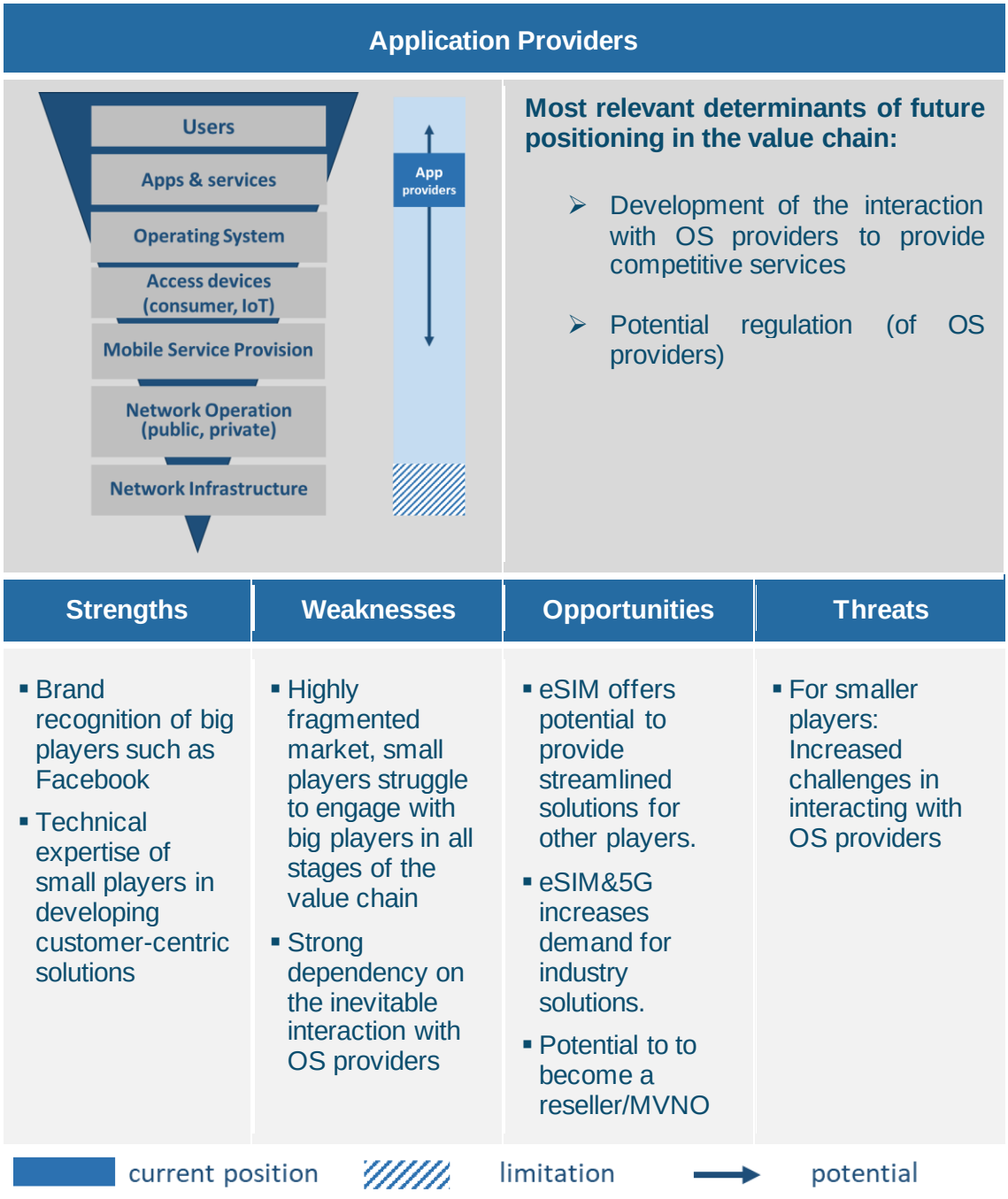
Source: WIK

Figure 4-16: Impact of new technologies on OS providers – Summary



Source: WIK

Figure 4-17: Impact of new technologies on Application Providers – Summary



Source: WIK

5 Implications of new technologies for competition and consumer welfare

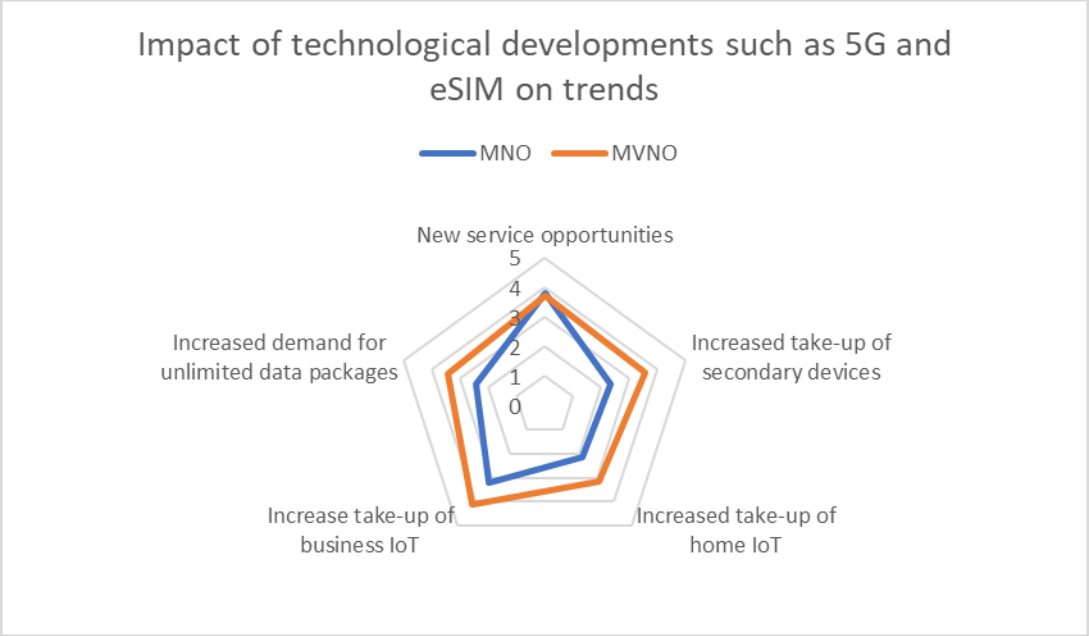
In this chapter, we consider what implications new technologies such as 5G and eSIM may have for consumer welfare and discuss to what extent players beyond MNOs, such as MVNOs and verticals could play a role in driving innovation in and demand for advanced services.

- The applications made possible by 5G and eSIM promise to offer significant value to consumers, industrial customers and the economy at large. However, if MNOs alone control the pace of deployment of full 5G capabilities, there is a risk that the benefits to enterprises could be delayed or that services may not meet the specific needs of larger businesses. In addition, the 5G transition could be associated with a reduction in choice, and potentially higher prices for consumers in countries where MVNOs have previously played a significant role in the market, but have not be able to offer competitive services via 5G. Customers which rely on legacy devices for their general communication services or for applications such as alarms will also be impacted by the switch-off of 2G and 3G networks that is likely to follow the deployment of 5G. The move towards all-digital processes for sign-up and customer service could also impact certain customer groups.
- Case studies on manufacturing, automotive, travel and other sectors suggest that specialist MVNOs and verticals could play a valuable role in supporting innovation and boosting demand for services provided via 5G and eSIM, if enabled to exploit the full potential of these technologies.
- Consumer MVNOs could also play an important role in supporting competition in 5G-based data intensive services, in particular in markets which would otherwise lack a competitive dynamic in mass-market mobile services.
- The degree to which consumer MVNOs can affect outcomes in terms of price and quality of 5G-based services depends on whether wholesale access conditions give access to the latest technologies and permit them to differentiate their service from that of their host. Consumer MVNOs have also historically played an important role in providing value offers for vulnerable customer groups or those which prefer physical interaction (e.g. in post offices or supermarkets), and could potentially play a valuable role in continuing to support such customers in a 5G context where mainstream providers may opt for all digital solutions.

5.1 Prospects for competition and consumer welfare in the status quo

Available approaches to measure the impact of 5G suggest that substantial economic value could be realized in theory, in particular in the industrial segment, but also in increasing the potential for end-users to benefit from advanced services for professional as well as personal use.[179] Indeed, as shown in the following chart, MNOs and (to an even greater extent) MVNOs surveyed for this study consider that 5G and eSIM will provide scope for new service opportunities and could contribute to the increased take-up of business IoT, as well as boosting demand for secondary devices and unlimited data packages.

Figure 5-1: Impact of technological developments such as 5G and eSIM on product and service trends



Source: WIK-Consult survey responses Q4 2022

However, the slow pace of roll-out of 5G SA in the EU, uncertainty around key use cases by MNOs[180] and hesitance amongst verticals regarding the net benefits of 5G as cited in interviews, suggest that it may be some years before Europe taps into the full industrial potential of 5G. The slow pace of take-up of eSIM in an industrial setting and continued

179 See for different quantitative forecasts on the global 5G impact World Economic Forum (2020): The Impact of 5G: Creating New Value across Industries and Society, White Paper in collaboration with PwC, January 2020, https://www.pwc.com/gx/en/about-pwc/contribution-to-debate/wef-the-impact-of-fiveg-report.pdf page 9-10.

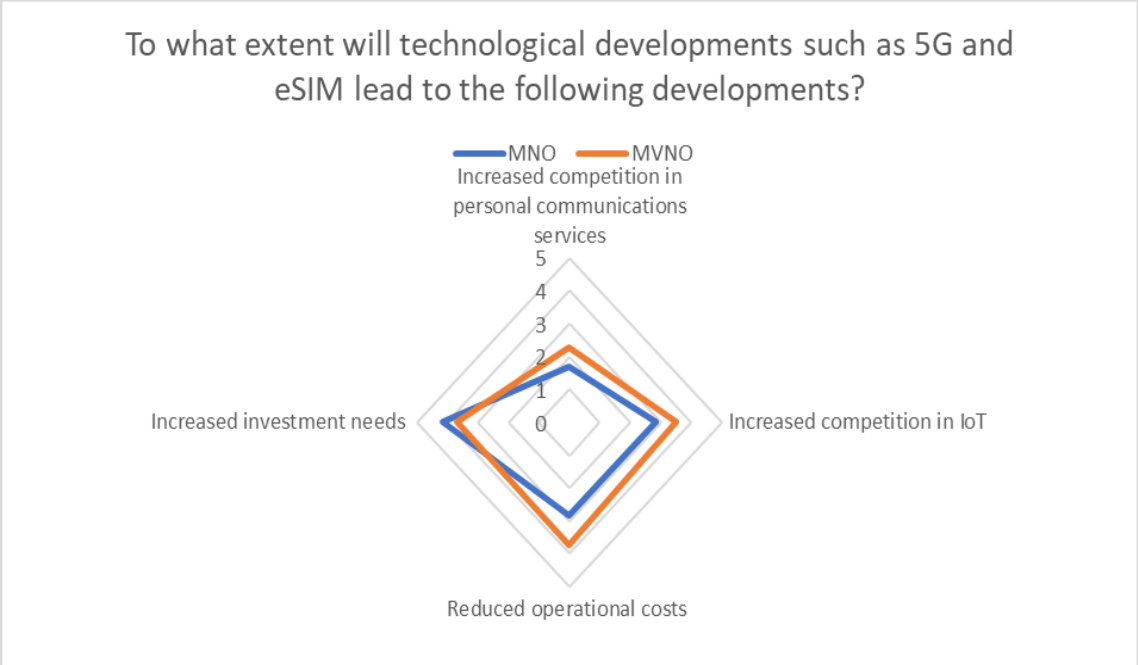
180 MNOs all state their intention to offer services based on 5G SA but are mostly still engaged in an exploratory process to understand which use cases could be commercialised.

concerns by verticals around switching processes even in the presence of eSIM reinforce this trend.

At the same time, while manufacturers and MNOs are supporting the diffusion of eSIM and (basic) 5G in the consumer segment, delays in or inadequate conditions for 5G MVNO access alongside a lack of support by key consumer equipment manufacturers could limit the ability of MVNOs to offer full service capabilities to their customers. As a result, both customer choice and the potential for additional competition and innovation in higher value unlimited data offers might be limited.

In this context, it is interesting to note that MNOs responding to the survey highlight that while they expect 5G and eSIM to result in some increased competition in IoT, the technologies are not expected to be linked to increased competition in personal communication services. At the same time, both MNOs and MVNOs highlight the significant investments that will be required to upgrade networks and services, which will not in the view of MNOs be wholly compensated through reduced operational costs.

Figure 5-2: Stakeholder perspectives on the impact of 5G and eSIM on competition and investment



Source: WIK-Consult survey responses Q4 2022

In practice, the evolution of competition in 5G-based services is likely to vary between different countries. Countries which benefit from strong competitive pressure arising from infrastructure-based competition between MNOs while achieving cost synergies (which

could include suitable network sharing arrangements)[181] should in theory support intense competition in retail markets including in high-end unlimited data offers, while offering wholesale opportunities to MVNOs which can expand the market including through the provision of innovative services to enterprises. However, if competition is not effective, and if there are limits on the degree to which other actors (including MVNOs and verticals) can enter and innovate in the consumer space or industrial applications, this could limit demand for bandwidth and quality-assured applications. This trend could in turn dampen the demand-side case for investment in 5G, although access to capital for investment by MNOs could be increased in this scenario. Concerns about competition on 5G in the status quo could be raised for example in countries where remedies were considered necessary in the context of 4G,[182] market structures remain unchanged and wholesale agreements have not been adapted to reflect 5G trends such as demand for unlimited bandwidths.

Even if bottlenecks at the level of access networks are not present, the potential for disruptive competition from smaller MNOs and consumer MVNOs could be limited if leading equipment manufacturers and OS providers exercise control over connectivity and access to features on the device, although this same control could also benefit MVNOs specialising in global connectivity and contribute to increased bargaining power for these MVNOs in relation to MNOs if they are given preferential treatment for the provision of connectivity in certain (presumed secondary) devices by OEMs/OS providers.

As regards the evolution of the situation for consumers, in competitive markets there should be sufficient dynamic between the MNOs to support increases in quality while maintaining a competitive price. The competitive dynamic in such markets and in particular markets where at least one of the players has spare capacity may also lead to commercial MVNO agreements being reached which increase the range of choice for consumers. On the other hand, consumer choice may be reduced and prices may be relatively higher in markets where such a competitive dynamic is not present, and where MNOs are reluctant to offer 5G access at competitive rates through their sub-brands. The impact on quality in the absence of strong competitive constraints may however be ambiguous, depending on whether MNOs utilize additional cashflows to invest in their network or instead seek to raise margins.

181 See Godlovitch, I.; Wernick, C.; Sörries, B.; Strube Martins, S.; Knips, J.; Wissner, M.; Tenbrock, S.; Franken, M. (2019): Analysis of the Danish Telecommunication Market in 2030, December 2019, WIK-Consult study for the Danish Energy Agency, https://www.wik.org/fileadmin/Studien/2020/Analysis_of_the_Danish_TK_Market_in_2030.pdf (last accessed on 24.03.2023).

182 Such concerns have been raised for example in the Austrian market and a review by the NRA is ongoing.

Verticals should be key beneficiaries from the deployment of eSIM and 5G, and most of those which responded to the survey considered that they should benefit from increased choice and the availability of quality assured services as a result of the deployment of technologies such as 5G and eSIM. However, in the status quo, if wholesale access remains challenging in certain jurisdictions there is a risk that verticals which require seamless global connectivity may not secure the connectivity they need. This was highlighted as a concern by a car manufacturer responding to the survey, and applies beyond 5G. Choice in quality assured services for enterprises may also be limited if, as seems likely, there are delays for industrial MVNOs in obtaining the full capabilities of 5G SA[183] and/or if there are no realistic alternative options for verticals to obtain or lease spectrum to deploy their own private networks where this would be a viable solution (mainly limited to larger businesses with connectivity requirements in specific locations). Another consequence of limiting the potential to deploy 5G SA to MNOs (or MVNOs relying on wholesale access) is that the availability of full 5G capabilities to verticals could be delayed compared with a situation where they have the potential to directly deploy (or commission others to deploy) private networks using their own spectrum, noting that 5G coverage obligations in spectrum licenses granted to MNOs may not have specified the QoS to be delivered.

Meanwhile, if solutions are not found to improve switching processes for IoT eSIM, enterprises deploying IoT solutions may continue to face lock-in challenges and high switching costs relating to connectivity. Consumers may also face lock-in and/or "after market" cost challenges in cases where consumer IoT and secondary devices are provided with connectivity pre-selected and where there is no straightforward interface to select an alternative provider. Another development that will affect certain end-users is that MNOs either have or are planning to switch off legacy 2G and 3G technologies. This could create challenges for consumers with legacy devices (or for certain IoT devices). The move away from physical in-store sales and support towards all-digital sales channels that is likely to be the end-game with eSIM deployment could also disadvantage customer groups which have challenges in going online.

5.2 Potential for alternative players to support competition and innovation in the transition to 5G

MNOs are and will continue to be the primary investors in 5G connectivity, and will play a pivotal role in meeting customer needs in the 5G environment. However, it is possible that the pace of innovation and take-up of new services could be accelerated if there is greater scope for stakeholders beyond MNOs to directly deploy or to access (when

183 Interviewees from the IoT sector have noted that, as MNOs compete with specialized IoT MVNOs for verticals as large customers e.g. in the car sector, they have a disincentive to grant access to these MVNOs to favourable conditions.

deployed) the full capabilities of 5G. We consider the role that alternative players could play in enriching 5G service provision and boosting demand, while noting that any potential positive effects from increased competition of this kind should also be considered in relation to the impact that boosting infrastructure or service competition may have on the investment incentives of and business case for MNOs.

5.2.1 Innovation potential from specialist MVNOs

There are indications to suggest that IoT MVNOs in particular have the capability to add value to the market and support take-up of new technologies by a variety of industrial players.

The fact that MVNOs have won major contracts to supply connectivity and applications to car manufacturers such as the Volkswagen Group (Cubic) and companies such as Jaguar Land Rover, Fiat and Alfa Romeo (Transatel) provides evidence of their potential value add. Transatel explains that MVNOs can offer car manufacturers the potential to regain control over the services they provide, including control over the security of their network and economics, noting that major platforms levy a substantial charge for the use of their app stores and associated infrastructure. Transatel also observes that there is considerable scope in innovation in in-car services (including alongside telematics and predictive maintenance, apps for drivers (e.g. charging points, autonomous diving), entertainment apps for passengers and apps for third parties such as insurers. The development and management of this application ecosystem could provide a differentiating feature for global car manufacturers. Another benefit to verticals of using MVNOs rather than contracting with an MNO is the option to switch to different mobile service providers in different countries, according to Transatel. Transatel notes that there is limited interest from verticals in 5G for QoS control today. To ensure that the potential of this technology flourishes, there will be a need to have MVNOs which are innovative in IoT / technical aspects and business development.

Specialized MVNOs for IoT have also played a role in supporting the development of other IoT solutions such as the tracking of shipping containers. Operators such as EMnify, Things Mobile, Onomondo and 1nce, have focused on this particular use case and are experts in using special, resistant SIM cards (e.g. against heat, corrosion) and often offer “pay-as-you-go” pricing models in which customers pay the same price per megabyte in a wide range of countries. Their business model relies on the use of multi-IMSI SIM cards and/or using international numbering spaces, and involves establishing roaming contracts with more than one MNO per country to maximise coverage. This business could be expanded in future through the use of 5G SA to further facilitate support for mMTC, the massive use of IoT devices in a dense space.

Services such as these can also be facilitated through MVNEs acting as white label providers (e.g. Simfony, NewSIM), which contract with MNOs around the world, provide the technical backend and deliver customer service for MVNOs. This may enable IoT MVNOs to focus on branding and to provide additional, technical services.

Further case studies illustrating the role that can be played by specialized MVNOs in supporting innovation in IoT, are provided in a 2019 study by WIK-Consult for the European Commission.[184]

Turning to secondary services, innovation and value added for the mass market can also be seen in the role played by specialised MVNOs in developing eSIM-based services for travelling, which can significantly lower the cost of travel connectivity. in cases where otherwise roaming charges would otherwise be set at a high level.[185] An example of the extent of savings achieved by eSIM-supported competition can be seen in the cost of data when travelling to the United States. While an eSIM profile with 10 GB data volume costs 24 Euro through Ubigi (travel brand of Transatel)[186] and 22.50 Euro through Nomad[187] some MNOs charge considerably more: Orange (France) offers 10 GB US data for 29 Euro per month[188], the German branch of Deutsche Telekom only offers 3 GB for a price of 49.95 Euro[189] while Eir in Ireland charges 29.95 for 1 GB of US roaming data.[190]

5.2.2 Potential for innovation from verticals

Experience shows that verticals can also play a valuable role in the development of new 5G and eSIM-enabled use cases. Here, we provide examples of 5 use cases in which verticals are using or exploring key features of 5G and eSIM to drive innovation and boost competition.

Manufacturing

The German manufacturing company Bosch deployed their first 5G private networks with locally assigned frequencies in 2019 at their factory in Stuttgart together with Nokia[191]

184 See Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, J.S.; Taş, S. (2019): Technological developments and roaming, WIK-Consult report for the European Commission, https://op.europa.eu/en/publication-detail/-/publication/7c74b70b-b4d8-11e9-9d01-01aa75ed71a1 (last accessed 19.12.22).
185 In the EU, this issue has been addressed through roaming regulation. However, high roaming charges persist in other jurisdictions.
186 https://cellulardata.ubigi.com/data-plans-and-coverage/ (last accessed on 01.02.23)
187 https://www.getnomad.app/ (last accessed on 01.02.23)
188 https://boutique.orange.fr/options/pass-usa-canada (last accessed on 01.02.23)
189 https://www.telekom.de/unterwegs/tarife-und-optionen/roaming/travel-surf (last accessed on 01.02.23)
190 https://www.eir.ie/roaming/#/America1/usa (last accessed on 01.02.23)
191 For other projects described, Bosch works together with different equipment manufacturers such as Ericsson or Qualcomm. It is possible that verticals would be more dependent on single vendors when their networks would be deployed by MNOs.

and plans to roll 5G out gradually to all 250 plants around the world.[192] According to an interview with Bosch for this study, the main challenge is the integration of this new private network into the existing IT at the company site.

If these challenges can be addressed, this could support the wider diffusion of several applications that Bosch is currently testing in trials. One such application is cloud-based automated mobile robots, that transport parts in a semiconductor factory in Reutlingen.[193] Another application that benefits from the precision and low latency enabled by 5G SA is the use of robots to conduct the automatic inspection of manufactured parts.[194] A particular advantage of 5G manufacturing is that it enables greater flexibility for machines to be moved around, offering the potential to rearrange production lines quickly and often based on current needs.[195]

Energy

The energy network provider ESB networks in Ireland uses the possibilities of new technologies in two separate areas: Smart metering and smart grid control.

The **smart meter** use case makes use of eSIM to give the company more bargaining power towards potential suppliers of connectivity. When the rollout of smart meters was announced in 2017, ESBN decided that eSIM should be mandatory in the new devices. A key reason was to make it easier to switch connectivity provider at a later stage. Without eSIM, switching operators would not have been feasible and unlikely to be performed, as it would have meant manually switching millions of SIM cards, leading to lock-in with the initial partner. By 2024, ESBN plans to deploy 2.3 million smart meters in Ireland.[196]

In the area of **smart grids** (smart energy networks), ESBN is building its own network based on frequencies at around 450 MHz[197]. According to information given in an interview for this study, the operator is currently procuring equipment, which will initially be based on 4G/LTE, but could, depending on the manufacturer, be upgradeable to 5G. An independent network for the smart grid is necessary as there are applications for which

192 https://www.bosch-presse.de/pressportal/de/en/bosch-puts-first-5g-campus-network-into-operation-221632.html (last accessed on 24.03.2023).
193 https://5g-acia.org/testbeds/testbed-5g-smart-testbed-in-bosch-semiconductor-factory/ (last accessed on 24.03.2023).
194 https://www.rcrwireless.com/20220630/5g/qualcomm-bosch-rexroth-make-industrial-5g-real (last accessed on 24.03.2023).
195 See: https://www.industry-of-things.de/wie-bosch-rexroth-sich-die-factory-of-the-future-vorstellt-a-1094067/ (only available in German, last accessed on 24.03.2023).
196 See also Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf.
197 ESB Networks won an auction for the frequencies of 410-414 MHz as well as 420-424 MHz for 1.1 million Euro in 2019, see https://www.comreg.ie/comreg-completes-the-400-mhz-spectrum-award/ (last accessed on 24.03.2023).

the public “best-effort” service by the MNOs is not sufficient, such as AMI (advanced metering infrastructure), which relies on real-time monitoring of energy usage to control the grid accordingly. While ESBN initially plans to choose an external operator for the network, it is their goal to have it self-run in the long term.

Automotive

For manufacturers of connected cars[198], seamless and easy to establish network access is one issue that would facilitate the deployment of their cars worldwide. Finding a partner that can offer global connectivity is key as today manufacturers often need to use different connectivity partners on different continents, and this can complicate the provision of services. The greatest challenge are countries that have requirements for the use of local infrastructure for certain technologies (e.g. eSIM in Turkey). Access to 5G in all countries makes the offering of entertainment services that have higher bandwidth requirements easier (e.g. in-car video streaming), and this will also apply for potential autonomous driving features in future, which will require the rollout of 5G SA networks and access to the network capabilities in all relevant countries. A reliable connection may potentially also open up the potential for new revenue streams through the analysis of different kinds of data collected by the car. Currently, Volvo is working with the Swedish and Norwegian authorities to share anonymized data about road conditions for road maintenance purposes.[199] Due to the long development time, the sales cycle and the device lifetime of cars, Volvo notes that today’s decisions about what is built into a car will affect the global fleet far into the 2030s. eSIM is therefore crucial as it enables the potential to switch operators. This way, car manufacturers not only increase their bargaining power but leave options open to partner with different players (including IoT MVNO specialists) even for vehicles that are already deployed.

Cities

The city of Barcelona, has not yet launched its smart city services on a large scale[200], but is involved in a pilot project focused on mobility and security. In the mobility trial, the City is testing applications involving connected cars and platforms to manage these cars. This application requires 5G standalone networks to benefit from ultra low latency (URLLC) and will serve as a step towards developing the car communication needed for

198 Insights for this study were given through an interview and survey answers by Volvo.
199 https://www.media.volvocars.com/us/en-us/media/pressreleases/157065/volvo-cars-puts-1000-test-cars-to-use-scandinavian-cloud-based-project-for-sharing-road-condition-in (last accessed on 24.03.2023).
200 They already offer a public WiFi network for more than 10 years with 600 outdoor and 600 indoor sites but no 5G network yet. This offers the potential for synergies should a private 5G network be rolled out by the city, e.g. regarding the use of fibre infrastructure to connect the antennas.

autonomous driving.[201] As regards security and additional services, Barcelona is part of the 5GCat project[202] which encompasses different use cases:

- Transmission of holographic images to meeting rooms via 5G
- Health monitoring and connected devices for policemen which provide information to establish a more secure environment (e.g. with automated processes to enable body cameras when guns are drawn).
- In case of fires in remote areas, trucks equipped with 5G equipment could be used to forward satellite connectivity to a broader area and use it to remote control firefighting robots[203]
- 5G delivers the connectivity needed to detect car traffic, tram traffic and car accidents through camera data simultaneously and in real time.

Although it has not yet made a decision to invest in 5G, the City notes that a self-run private 5G network could offer significant benefits as the city would not be reliant on MNO deployments to make use of innovative services and to attract companies that use the 5G network. In addition it would leave the city in control of the assets (including spectrum, if private spectrum were be granted) and reduce potential lock-in-effects.

Similarly to Barcelona, Dublin City Council has not yet invested in 5G. They have test accounts in place to support smart city projects, but currently rely on technologies such as NB-IoT, Sigfox and Lorawan to support their services. They note that M2M involving sensors is already deployed across multiple city council services for purposes such as flood monitoring and waste management. They consider that over the next 2-3 years demand for quality assured services could emerge to support emergency services and traffic operations, as well as event-specific video streaming, and potentially in future, support for drones. However, they consider that most use cases can be served through 4G and Low Power Wide Area Network solutions. They consider that pricing is a key issue limiting 5G take-up, and note that "understanding the business models" on both sides (vertical and MNOs) will be important for 5G industrial use cases to emerge.

Healthcare

Under the headline "From Healthcare to Homecare", Ericsson published a study in 2017, predicting that 5G would make healthcare more decentralized.[204] This would be achieved

201 https://5gbarcelona.org/pilots/5g-connected-car/ (last accessed on 24.03.2023).
202 https://pilot5gcat.com/en/ (last accessed on 24.03.2023).
203 A similar system is also tested by researchers in Germany, where the dedicated spectrum for verticals is used to deploy the 5G private network in case of a fire: https://www.fraunhofer.de/en/press/research-news/2022/may-2022/temporary-local-5-G-network-to-help-fight-forest-fires.html (last accessed 24.03.2023).
204 See Ericsson (2017): From Healthcare to Homecare – The critical role of 5G in healthcare transformation, June 2017, https://www.ericsson.com/4ac62e/assets/local/reports-

through wearables that give the opportunity to monitor patients' status live and administer medication remotely. While 5G is not absolutely necessary for this kind of application, it may alleviate concerns from patients and health care providers about sub-par service due to network coverage/reliability issues. Other significant 5G use cases in healthcare include AR applications, to stream video of an injured person live to a physician in a hospital, and to receive assistance, particularly in rural areas. Hospital devices and equipment could also be managed more efficiently when tracked through 5G.[205]

Private networks for hospitals could also allow additional innovation. Through the low latencies and the high reliability of a private 5G network, expert surgeons could operate a robot to perform the surgery remotely from hundreds of kilometres away. This was already tested successfully and may in the future be supported by VR headsets for the surgeon to get an even better view of the patient.[206]

5.2.3 Innovation potential of consumer MVNOs

Consumer MVNOs can play a role as well in driving innovation and supporting competition in mobile connectivity. However, there is a debate concerning the circumstances in which they can play this role, and what types of benefits they can bring.[207]

An analysis by Calzada and Martínez-Santos, which investigates prices from 20 countries from 2011 to 2014, concludes that MVNO presence as well as a low market concentration are associated with lower prices for mobile broadband.[208] However, more granular analyses within and across specific countries suggests that the effects of competition from consumer MVNOs can vary, and may also be influenced by the presence and nature of regulatory remedies. [209]

papers/consumerlab/reports/2017/healthcare-to-homecare_screen_aw2.pdf (last accessed on 24.03.2023).

205 The possibilities of 5G in healthcare are described and evaluated extensively in: 5G Health (2020): Whitepaper – The need for 5G technologies in the healthcare domain, July 2020, https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf (last accessed on 27.03.0223).

206 See https://uk5g.org/discover/5g-industry/health-social-care/5g-in-medical-treatment-UK/5g-remote-robotic-surgery-UK/ (last accessed on 27.03.2023).

207 A very detailed review of the existing literature can be found in: Godlovitch, I.; Knips, J.; Wernick, C.; Gries, C.; Lucidi, S.; Braun, M.R. (2021): The role of MVNOs in evolving mobile markets, WIK-Consult study for ComReg, https://www.comreg.ie/media/2021/10/ComReg-21101a.pdf (last accessed 19.12.22).

208 See Calzada, J.; Martinez-Santos, F. (2016): Pricing strategies and competition in the mobile broadband market, http://diposit.ub.edu/dspace/bitstream/2445/107806/1/668398.pdf (last accessed 19.12.22).

209 A model by Kalmus and Wiethaus implies that strong competitive pressure from MVNOs only happens if access is mandated through regulation as MVNOs would not be granted access otherwise. See Kalmus, P.; Wiethaus, L. (2010): On the competitive effects of mobile virtual network operators, in: Telecommunications Policy, Volume 34, Issues 5-6, Pages 262-269. Additional discussion can be found

Several studies covering markets in Australia and New Zealand by NERA Consulting found that MVNOs were not associated with price advantages, and concluded that they served specific niches rather than putting pressure on the mass-market.[210] However, the analysis may not have taken into account whether the wholesale conditions in the markets they studied allowed for price competition to the mass-market. MVNOs interviewed for this study have cited difficulties in obtaining timely access to the latest generations of technologies and/or pricing conditions (such as pay-per-use wholesale tariffs) as factors which have prevented them from competing aggressively in high-end data. Moreover, a study by WIK-Consult for the Swiss regulatory authority notes that to deliver innovation in product and pricing structure, there needs to be a certain degree of independence for the MVNOs to set their prices. Resellers can likely only bring very little innovation to the market.[211]

It is also relevant to note that MVNOs could have positive effects on the market beyond price competition. For example, research has found that service level competition by MVNOs may push MNOs to invest into a higher service level themselves.[212] Moreover, many MVNOs provide services targeted at specific customer groups that might otherwise be underserved such as immigrants seeking attractive pricing for specific destinations, or customers that prefer to purchase communications in a physical store such as Post Offices or supermarkets.

More than half of the 9 MVNOs responding to the online survey, said that MVNOs had contributed to increased competition for consumers as a whole as well as lower prices, innovation in customer service and innovation in services or bundles. MNOs were considerably less positive about MVNO's role in these areas, but nearly 40% of those responding agreed that they had contributed to increased competition to consumers as a whole and to providing competition in services for specific consumer groups in their jurisdictions.

---

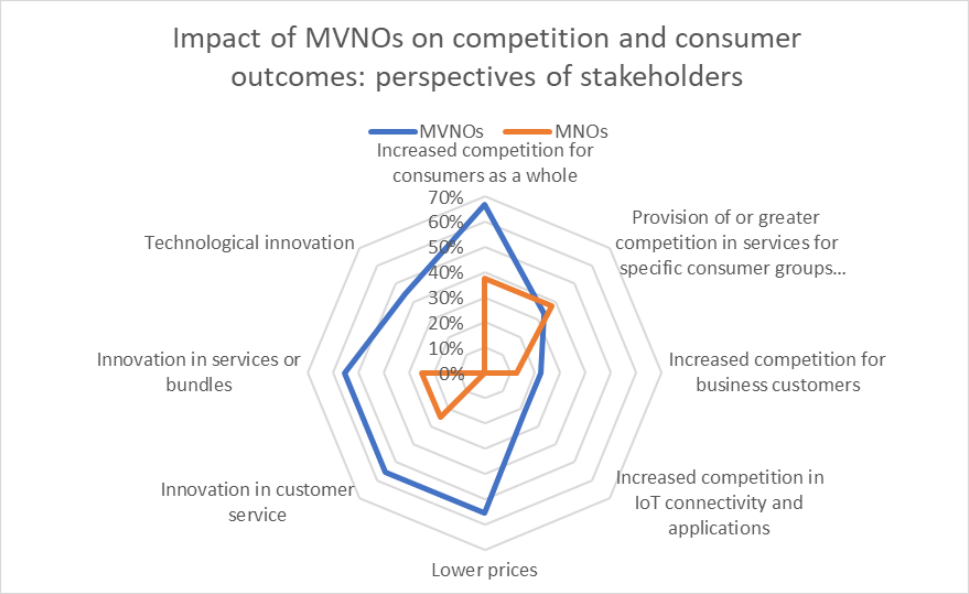
in: Godlovitch, I.; Knips, J.; Wernick, C.; Gries, C.; Lucidi, S.; Braun, M.R. (2021): The role of MVNOs in evolving mobile markets, WIK-Consult study for ComReg, https://www.comreg.ie/media/2021/10/ComReg-21101a.pdf.

210 See Spark New Zealand (2019): Review of Red Dawn Consulting Report – "MVNO landspace: Global perspectives and New Zealand Applications", https://comcom.govt.nz/__data/assets/pdf_file/0021/158412/NERA-report-for-Spark-Submission-on-mobile-market-study-preliminary-findings-28-June-2019.PDF (last accessed 19.12.22).

211 See Neumann, K.H.; Plückebaum, T.; Strube Martins, S. (2016): Network Sharing im Mobilfunk und Festnetz-Mobilfunk-Konvergenz in der Schweiz, WIK-Consult report for BAKOM, https://www.comcom.admin.ch/comcom/de/home/themen/mobilfunknetz/network-sharing.html (available only in German, last accessed on 24.03.2023).

212 See Streule, I.; Stewart, J.; Bellis, A. (2018): MVNO aspects of the Commission's mobile market review, report for Trustpower, https://comcom.govt.nz/__data/assets/pdf_file/0018/104238/TrustPower-Appendix-2-Analysys-Mason-Submission-on-the-Issues-Paper-26-October-2018.PDF (last accessed 19.12.22).

Figure 5-3: Impact of MVNOs on competition and consumer outcomes: perspectives of stakeholders



Source: WIK-Consult stakeholder survey Q3 2022

While as noted above, there are situations where MVNOs have been able to support price competition or provide other consumer benefits and where regulation has been needed to support this outcome, there are also situations where the involvement of MVNOs has not been necessary to provide positive outcomes for consumers. This seems to be the case in particular in markets which involve a disruptive player. These markets are likely to involve imbalances in market shares and spare capacity which provide incentives to fill the network, which can be achieved through aggressive pricing and product innovation as well as potentially through providing attractive terms for MVNOs to join the network. This situation may occur more frequently in 4 player markets, although is not excluded in markets with 3 players.[213] As an example, Bourreau et al. (2021) note that the entry of Free as the 4th MNO in France contributed to consumer welfare, in particular through increased variety and due to additional gains from the fighting brands.[214] This successful

213 See Godlovitch, I. et al (2018): Review of the Significant Market Power (SMP) Guidelines, report by WIK-Consult for the European Commission, April 2018, https://op.europa.eu/en/publication-detail/-/publication/6eebf7b9-4833-11e8-be1d-01aa75ed71a1/language-en (last accessed on 24.03.2023).

214 See Bourreau, M.; Yutec, S. and Verboven, F. (2021): Market Entry, Fighting Brands, and Tacit Collusion: Evidence from the French Mobile Telecommunications Market, p. 3494 ff. in: American Economic Review 2021, 111(11), pp. 3459–3499, https://doi.org/10.1257/aer.20190540 (last accessed on 19.01.2023).

entry of Free is deemed to have also been facilitated by beneficial regulatory conditions for the entrant.[215]

5.3 Conclusions regarding the role of wholesale mobile connectivity in supporting competition and consumer welfare

5G and eSIM could deliver significant value to enterprises, consumers and the economy as a whole. However, in the status quo, there is a risk that the full potential of 5G and eSIM may not be realised, as MNOs limit the promotion of eSIM and exercise caution around the deployment of 5G SA. At the same time, the technological shift could be linked to reduced competition at the network level (due to high investment costs) and at the service level (due to delays in adapting MVNO wholesale conditions). The shift in control over SIM installation from MNOs to OEMs/OS providers could enable new specialist MVNOs to enter the market but could also be associated with lock-in if options to choose or change provider are limited.

IoT MVNOs and verticals have shown that they are capable of driving innovation and boosting demand for services based on eSIM and 5G. Giving scope to a wider range of players to invest in industrial and IoT solutions as well as secondary services for consumers should in principle increase demand and accelerate the exploitation of these new technologies. Consumer MVNOs could also play a role in developing new service offerings and boosting demand in 5G. However, their scope to affect market outcomes is likely to be greater in markets which would otherwise lack effective competition, and is dependent on having wholesale conditions that enable them to act independently from their host at a technical and operational level, as well as in pricing.

215 See Berne, M.; Vialle, P. and Whalley, J. (2019): An analysis of the disruptive impact of the entry of Free Mobile into the French mobile telecommunications market, in: Telecommunications Policy, 43(3), p. 262-277, https://doi.org/10.1016/j.telpol.2018.07.007 (last accessed on 03.02.23).

6 Regulatory options

In this chapter we explore the solutions that have been applied to boost competition in mass-market and industrial mobile connectivity, and consider in which situations these solutions may have broader relevance. We also consider what tools might be available to address any issues arising from control over key functions at the OEM/OS layer and discuss strategies to ease the transition to 4G/5G by vulnerable consumers.

- Where competition in 5G mobile services is expected to be limited, possible solutions include reserving 5G spectrum for a new entrant or applying obligations relating to MVNO access. Previous experience suggests that new entry can boost attractive offers and innovation, but it might not always be feasible or economically viable.
- MVNO obligations can provide an alternative when infrastructure-based competition is not feasible. Where NRAs consider that MVNO obligations may be necessary, they will need to be justified based either on (joint) SMP or as a competition measure attached to spectrum licences. Existing spectrum-based obligations have generally been applied under the previous regulatory framework. Applying MVNO obligations under spectrum licences in accordance with the EECC will in future require a market analysis including assessment of the competitive conditions and impact of any obligations on investment, but (as auction outcomes cannot be pre-determined) could not require an assessment of the market power of specific companies. Where MVNOs are needed to stimulate competition in the retail market, the access conditions should enable MVNO to act independently from their host in relation to certain technical and operational functions (full MVNO) and pricing, as well as having the capability to make use of new network capabilities in a reasonable timeframe.
- In order to limit barriers to deployment and increase choice in the enterprise segment, several Member States have assigned 5G spectrum directly to verticals. This has proved to be successful in a number of cases. However, dedicated spectrum for verticals tends to be relevant to larger businesses with localised connectivity requirements and may not meet the needs of SMEs or businesses which require widescale coverage. Certain countries have addressed concerns around service to those groups by including a licence condition that MNOs should meet reasonable requests for quality-assured services or offer spectrum leasing.
- eSIM provides opportunities for greater competition in the supply of cross-border IoT, as well as the potential to switch provider for devices in the field, which was previously very complicated. However cross-border (and in particular global) IoT services inevitably rely to some extent on wholesale

international roaming. Attention to roaming conditions (including those provided to specialist IoT MVNOs) is therefore important in supporting competition in cross-border IoT. In addition, switching for M2M can present challenges in some situations due to the way in which the standard for eSIM is implemented for M2M.[216] This is another area which could benefit from improvements to standards, monitoring and possible guidance by BEREC.

- Problems relating to steering of connectivity or restrictions on switching by "gatekeeper" OEM/OS providers could be addressed under newly introduced provisions in the Digital Markets Act. It could also be explored whether the DMA could also address cases where OEM/OS gatekeepers limit access to certain functionality needed to support connectivity. However, the DMA is only applicable to platforms with gatekeeper status in "core platform services", and therefore may not resolve lock-in which is driven by OEMs such as car manufacturers bundling contracts for connectivity with the sale of vehicles. One solution could be to extend measures in the EECC which currently restrict ECS providers from engaging in lock-in, including SIM-locking of devices, to OEMs.

6.1 Possible solutions to foster competition in mobile connectivity

In cases where there are challenges which relate specifically to wholesale mobile connectivity, possible solutions can be sought in the context of the EU Electronic communications Code.[217]

6.1.1 Reserving spectrum for an entrant

If the problem is caused by a lack of competitive dynamism across mobile services in general including mass-market mobile services and there are reasonable prospects that the market can support an additional MNO, one solution may be to seek to encourage entry by reserving spectrum for a new entrant and/or introducing measures which could facilitate the entry and expansion of a new entrant such as national roaming provisions and lighter coverage obligations. Such measures could provide opportunities to disrupt a

216 Specifically, if the SM-SR is under the control of the former connectivity provider, its co-operation would be needed to switch to a new provider.

217 Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L1972 (last accessed on 22.12.2022) and Regulation (EU) 2022/612 of the European Parliament and of the Council of 6 April 2022 on roaming on public mobile communications networks within the Union, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R0612&qid=1671784618550&from=EN (last accessed on 22.12.2022).

market structure which might otherwise not be conducive to competition on prices or service innovation.

Where has new entry been achieved?

The following table provides an overview of countries within the OECD which achieved an increase in the number of MNOs between 2008-2020.

Table 6-1: Entry into mobile markets, 2008-2020

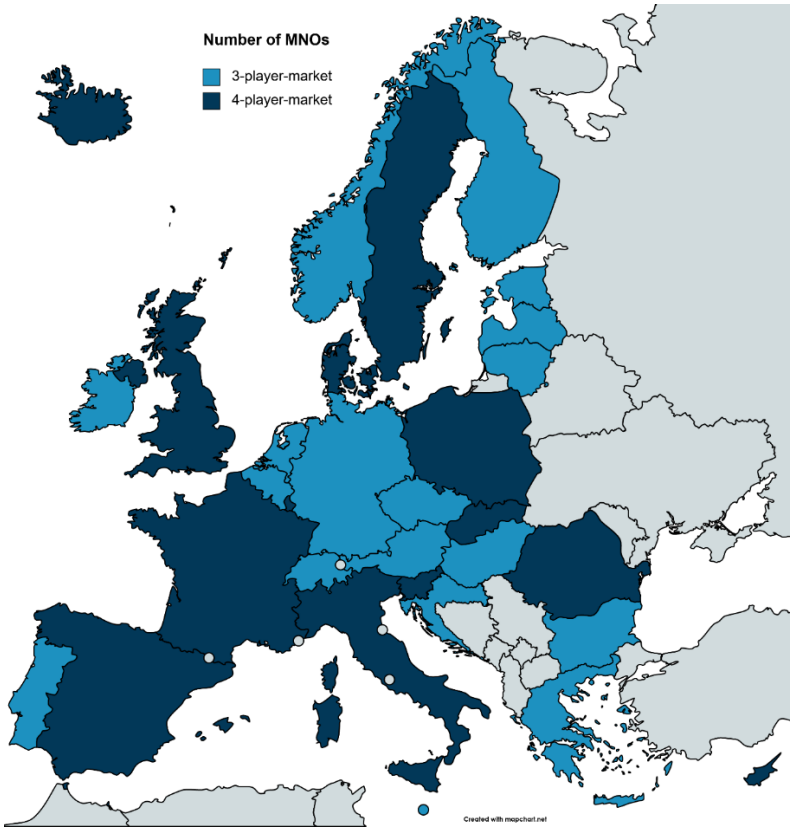
Year	Country	Number of operators	MNO entering the market
2008	Slovenia	3 to 4	T-2
2009	New Zealand	2 to 3	2Degrees
2009	Poland	4 to 6*	Aero2, Centernet
2010	Iceland	3 to 4	Hringidan
2012	Colombia	3 to 4*	Avantel
2012	France	3 to 4	Free (Iliad)
2012	Israel	4 to 5	Golan Telecom (Iliad)
2012	The Netherlands	3 to 4*	Ziggo Liberty
2015	Chile	3 to 5	WOM enters market
2015	Slovak Republic	3 to 4	4ka (SWAN Mobile)
2015	The Netherlands	4*	Tele2
2016	Lithuania	3 to 4	AB Lietuvos radijo ir televizijo centras
2016-18	Italy	3 to 4	Iliad Italy
2017	Hungary	3 to 4	MVN Net
2018	Israel	5 to 6*	We4G
2019	Germany	3 to 4	1&1 (former MVNO)
2020	Colombia	3 to 4*	WOM
2021	Portugal	3 to 4	NOWO (MasMovil) and Dixarobil
2024*	Belgium	3 to 4	Citymesh/Digi Communications*
2021	Croatia	3 to 4	EOLO

Notes: * In the Netherlands: Ziggo (Liberty Global) entered the market in May 2012, and then merged Q4 2016; with Vodafone; Tele2 entered the market January 2015 merging in Q1 2019 with T-Mobile; at present there are only three MNOs. In Israel: Iliad (Golan Telecom) entered the market in 2012, and We4G (018 Xfone) entered in April 2018. However, Pelephone (Bezeq) has declared to be in deep financial problems since 2018, so may exit the Israeli market. In Colombia: WOM entered the Colombian market in 2020. In Belgium, Digi Communications has partnered with B2B player Citymesh to acquire the necessary spectrum and deploy a nation-wide mobile network. The spectrum was acquired by Citymesh Mobile, a JV co-owned by Citymesh and Digi Communications. Entry is expected in 2024. The data for Poland is only exemplary, there were several other entries during the time frame based on information by the regulator UKE: Sferia, Mobyland, Centernet,

Aero2, Nordisk Polska S.A (providing services in the CDMA technology in the 420 MHz band, as well as it was testing the dispatcher communication/connectivity in the LTE technology). Currently due to mergers and acquisitions, there are again 4 mobile network operators.

Source: WIK based on OECD (2021): Emerging Trends in Communication, OECD Digital Economy Papers, September 2021, No. 316, https://doi.org/10.1787/4ad9d924-en (last accessed on 03.02.2023) and homepage of the NRAs in Germany, Portugal, Belgium und Croatia.[218]

Figure 6-1: Number of mobile network operators in selected countries in Europe as of 2022.[219]



Source: Map created by WIK-Consult with mapchart.net based on information in Bahia, K. and Castells, P. (2022): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed in 19.12.2022).

As regards 5G specifically, according to responses to the survey conducted for this study, 5G spectrum has been reserved for new entrants in 6 Member States (Belgium, in the

218 https://www.bundesnetzagentur.de/cln_112/DE/Home/home_node.html, https://www.anacom.pt/, https://www.ibpt.be/operateurs and https://www.hakom.hr/en/home/8.

219 "The data…covers 29 European countries – 26 of the 27 members of the European Union plus the UK, Norway and Switzerland." The authors of this map "included operators that had a market share greater

900 MHz, 1800 MHz, 2100 MHz and in the 700 MHz band, Czech Republic in the 700 MHz Band, Finland/Greece/Italy in 700 MHz band Portugal in the 900 MHz and 1800 MHz bands). Spectrum can also be reserved for newcomers indirectly by placing a spectrum cap on the band (eg in Belgium a cap of 100 MHz was introduced at 3600 MHz, leaving up to 100 MHz available for newcomers).

Table 6-2: Spectrum reserved for new entrants in the context of 5G auctions

Country	Year	Spectrum for new entrant	Spectrum for new entrant
Belgium	2022	900 MHz, 1800 MHz, 2100 MHz, 700 MHz	Citymesh/Digi Communications*
Czech Republic	2020	700 MHz	-
Finland	2016	700 MHz	-
Greece	2020	700 MHz	-
Italy	2018	700 MHz	Iliad
Portugal	2021	900 and 1800 MHz	NOWO and Dixarobil

Notes: * Spectrum was acquired by Citymesh Mobile, a JV co-owned by Citymesh and Digi Communications.

Source: WIK survey and NRA websites.

Reservation of spectrum in 5G spectrum assignments has resulted in market entry in some cases. Entrants in the mass market include for example 1&1 (formerly an MVNO in Germany), which acquired spectrum in 2019, and NOWO (MásMovil) and Dixarobil (Digi Romania) in Portugal in 2021, while in Belgium, spectrum has been awarded to a JV co-owned by B2B provider Citymesh and Romanian telecommunications group Digi Communications. The companies are cooperating on the deployment of a country-wide network that will enable Digi to compete in the consumer market with entry currently planned for 2024.[220]

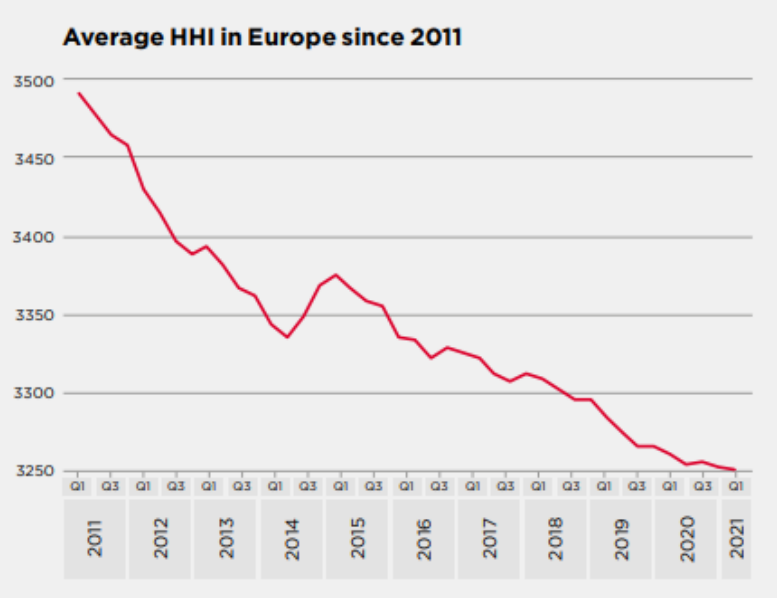
than 3% at some point in the period of analysis…The operators included in the analysis accounted for more than 99% of mobile connections in the 29 countries over the period." Bahia, K. and Castells, P. (2022): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed in 19.12.2022). Data for Cyprus was added by WIK-Consult. In Belgium, Germany and Portugal a fourth mobile operator acquired a spectrum license recently.

220 Citymesh and DIGI win spectrum in the auction and will start building a nationwide network (cegeka.com) ; Roemeens Digi gaat op alle fronten concurrentie aan op Belgische telecommarkt | De Tijd

Impact of entry on competition and pricing

In tandem with market entry, market concentration as measured by the HHI in Europe has declined since 2011 (see figure below).

Figure 6-2: Average HHI in Europe since 2011

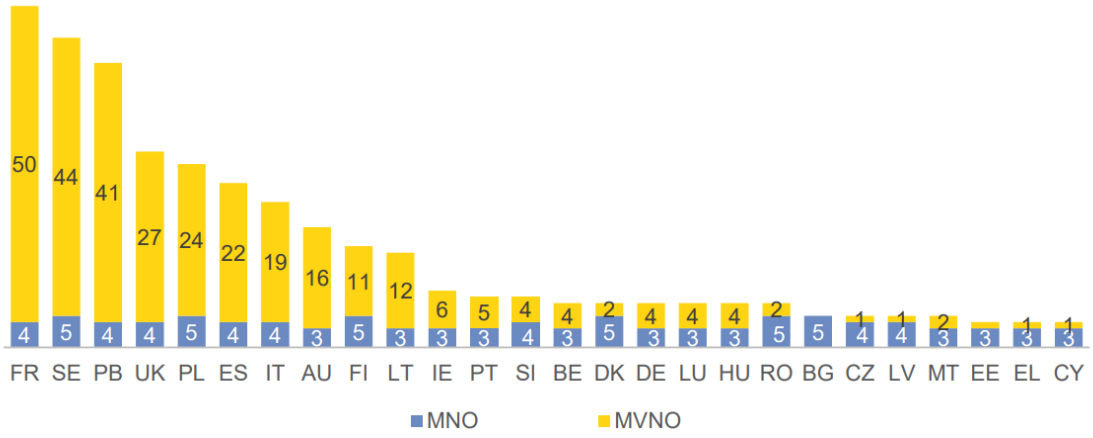


Source: GSMA (2022): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed on 07.02.2023).

In addition to providing direct competitive impetus, supporting the entry of an additional player (where economically viable) could potentially improve the conditions for wholesale access for IoT MVNOs (as well as consumer MVNOs if there is demand for additional consumer-oriented service), as a new entrant without a significant retail customer base of its own is likely to have incentives to fill its network.[221] The figure below provides a snapshot of the number of MNOs and MVNOs in European countries in 2019, illustrating that countries with 4 or more MNOs often (although not always) support the highest number of MVNOs, often on the basis of commercial agreements.

221 As such existing MVNOs could also play a role in supporting the business model for a new entrant.

Figure 6-3: Number of MNOs and MVNOs in the European Union in 2019



Source: ANACOM (2021): Operadores Móveis Virtuais em Portugal, Relatório, https://www.anacom.pt/streaming/MVNOemPortugal_maio2021.pdf?contentId=1644333&field=ATTACHED_FILE (last accessed on 16.02.2023).[222]

Awarding spectrum to a full-service mobile operator could also increase the competitive options available for verticals, but may not be considered a substitute for direct spectrum assignment, if the vertical has specific needs that it considers are best met through deploying a private network directly.

In a 2014 report the OECD found that a higher number of operators in a market was associated with enhanced innovative activity leading to all companies improving their services as regards price and quality.[223]

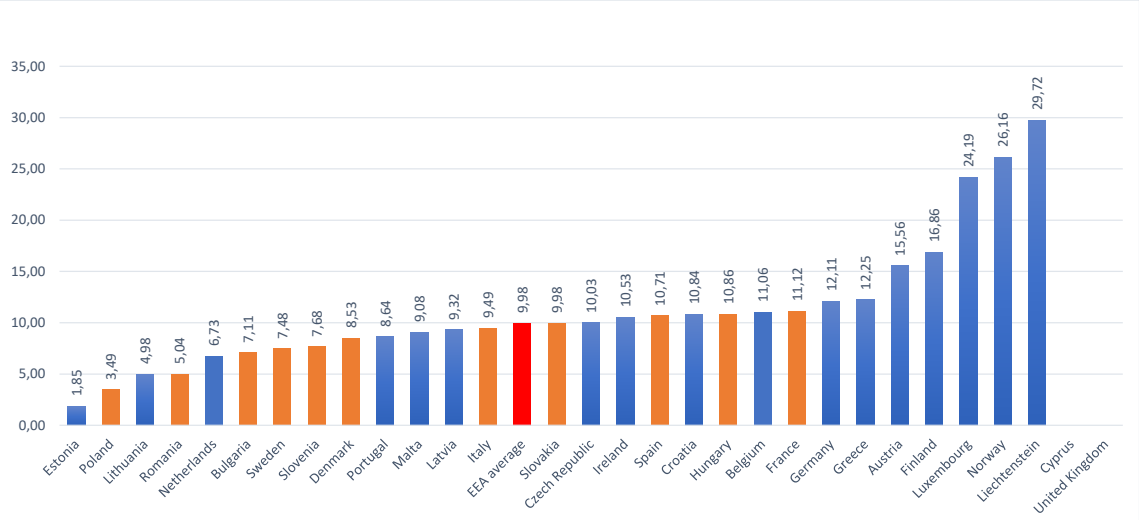
These findings have been corroborated by post merger analysis which found a price increase following mergers in countries that have reduced the number of MNOs. A study from 2017 using a dataset of 33 OECD countries over the period of 2002 to 2014 found that concentration in mobile markets led to retail price increases.[224] European countries with four MNOs, where four-three mergers were blocked or a fourth MNO entered the market (e.g. Italy, France, Denmark, and the United Kingdom), seem to have more attractive mobile data plans than two of the countries that experienced a reduction in MNOs (e.g. Germany and Austria). These findings were confirmed in a 2018 study by BEREC which found some evidence of increased retail prices for new customers

222 Different to what is displayed in the figure, Finland has 4 mobile network operators instead of 5.
223 OECD (2014): "Wireless Market Structures and Network Sharing", OECD Digital Economy Papers, No. 243, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxt46dzl9r2-en (last accessed in 07.02.2023).
224 Genakos, C.; Valletti, T. and Verboven, F. (2017): Evaluating Market Consolidation in Mobile Communications, cesifo Working Papers 6509 2017, https://www.cesifo.org/en/publications/2017/working-paper/evaluating-market-consolidation-mobile-communications (last accessed on 07.02.2023).

following 4 to 3 mergers in Ireland, Germany and Austria.[225] Conversely, a higher number of MNOs and lower market concentration (HHI) seem to be linked with lower mobile prices.[226] Axon notes[227] that studies conducted by regulators suggest that the entry of a 4th MNO, with a disruptive business model, can reasonably be expected to lead to reduced mobile retail tariffs in the range of 10-15%, at least in the short run.

These findings are supported by an international comparison of the ARPU for national mobile services, which shows that the seven countries with the highest ARPU are countries with 3 MNOs (in Germany and Portugal[228] a fourth MNO has entered the market recently).

Figure 6-4: Average Retail Revenue per User (ARPU) for national mobile services in Euro, Q1 2021 (Countries with 3 MNOs in blue, those with 4 MNOs in orange, Germany and Portugal with new entrant in 5G auction)



Source: BEREC (2021): International Roaming BEREC Benchmark Data Report October 2020 – March 2021, BoR (21) 115, https://www.berec.europa.eu/sites/default/files/files/document_register_store/2021/10/BoR_%2821%29_115_27th_BEREC_International_Roaming_Benchmark_Data_Report.pdf (last accessed on 07.02.2023), BIPT (2021): Communication du Conseil de l'IBPT du 4 mai 2021 concernant l'impact d'un quatrième opérateur de reseau mobile sur le marché mobile belge,

225 BoR (18) 119 BEREC Report on Post-Merger Market Developments – price effects of mobile mergers in Austria, Ireland and Germany https://www.berec.europa.eu/en/document-categories/berec/reports/berec-report-on-post-merger-market-developments-price-effects-of-mobile-mergers-in-austria-ireland-and-germany

226 https://www.cesifo.org/en/publications/2017/working-paper/evaluating-market-consolidation-mobile-communications (last accessed on 07.02.2023).

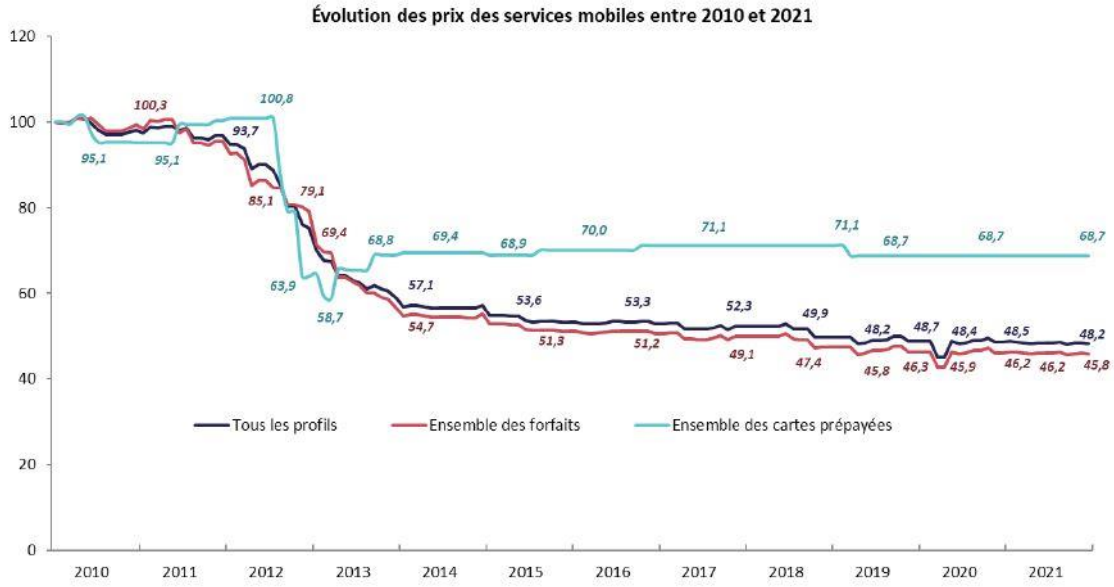
227 Axon (2021) Impact of 5G and a 4th mobile operator in Belgium https://www.bipt.be/operators/publication/axon-study-of-30-april-2021-on-the-impact-of-5g-and-a-4th-mobile-operator-in-belgium

228 In Portugal, 2 new entrants that acquired spectrum in the last multiband auction (NOWO and Dixarobil) are yet to offer mobile services supported on their network, they are still developing their mobile networks. NOWO is already in the market as an MVNO.

https://www.ibpt.be/file/cc73d96153bbd5448a56f19d925d05b1379c7f21/e6c9b38108e2129e8aeb7361c775d717f66c0ff6/communication_impact_quatrieme_operateur_reseau_mobile_belgique.pdf (last accessed on 03.02.2023). Countries with 3 MNOs in blue, those with 4 MNOs in orange.

Meanwhile, the impact of Iliad's entry in the mobile market in 2012 on reductions in mobile prices in France can be clearly seen from the following figure.

Figure 6-5: Development of mobile prices in France from 2010 to 2021



Source: https://www.arcep.fr/cartes-et-donnees/nos-publications-chiffrees/marches-des-communications-electroniques-en-france-enquetes-trimestrielles-et-annuelles/indice-des-prix-des-services-fixes-et-mobiles.html

Limitations relating to reserving spectrum for new entrants

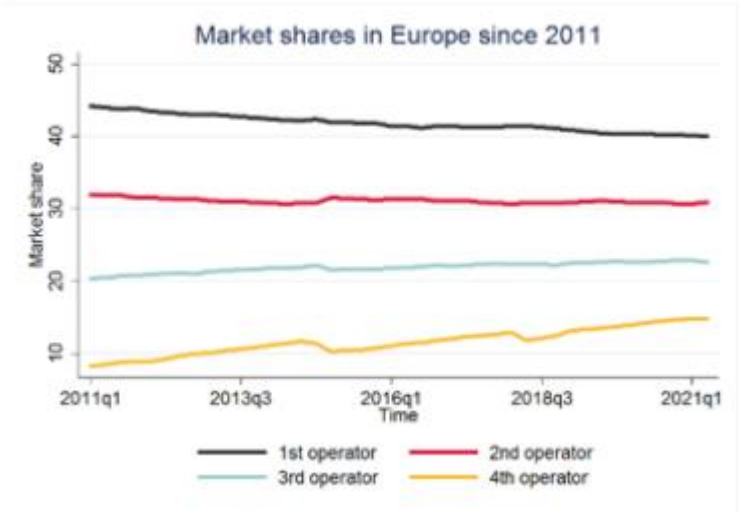
When entry is possible, it is notable that a late entrant often acts as disruptor and either introduces a product or service that supersedes existing ones, produces an existing product or service differently using new technologies or competes aggressively prioritising gains in market share over profitability.[229] Thus, reserving spectrum for an entrant or including the potential for spectrum acquisition e.g. in merger commitments may seem like an ideal solution.

However, experience suggests that not all markets can sustainably support 4 network operators, and that the potential for entrant depends not only on the overall size of the market, but on the ability of an entrant to build market share. The spectrum licensing

229 Ofcom (2016): A cross-country econometric analysis of the effect of disruptive firms on mobile pricing, Research Document, https://www.ofcom.org.uk/__data/assets/pdf_file/0019/74107/research_document.pdf (last accessed on 07.02.2023).

process has enabled market entry for (disruptive) mobile operators in some European countries. In particular, the licensing of 3G resulted in a large number of new entrants.[230] However, at the end of 2014, 18 of the new entrants had failed to launch their services. Those who did launch often attracted relatively few subscribers.[231] The example of CK Hutchison (trading as 3) which entered six different European markets and had just under 20 million subscribers by the end of 2014 showed that it took more than a decade to achieve this result and that this was only possible due to the patience and massive financial support of the parent company in Hong Kong.[232] The development of market shares of 1st to 4th operator in the market and the average CR2 show that on average it is difficult and a long term process for the third and fourth operator to gain market share.

Figure 6-6: Market shares in Europe since 2011



Source: Bahia, K. and Castells, P. (2022): The dynamic effects of competition on investment: the case of the European mobile communications industry, http://dx.doi.org/10.2139/ssrn.4175243 (last accessed in 07.02.2023).

230 According to Curwen and Whalley identify 46 new entrants as a result of the 3G licensing process across the EU. See Curwen and Whalley (2015): The licensing of mobile operators in European markets and the consequences of new entry for competition, Info 17 (3): 16-37, https://www.researchgate.net/publication/276442855_The_licensing_of_mobile_operators_in_European_markets_and_the_consequences_of_new_entry_for_competition (last accessed on 16.02.2023).

231 Michel Berne, Pierre Vialle, Jason Whalley, An analysis of the disruptive impact of the entry of Free Mobile into the French mobile telecommunications market, Telecommunications Policy, Volume 43, Issue 3, 2019, Pages 262-277, ISSN 0308-5961, https://doi.org/10.1016/j.telpol.2018.07.007.

232 Michel Berne, Pierre Vialle, Jason Whalley, An analysis of the disruptive impact of the entry of Free Mobile into the French mobile telecommunications market, Telecommunications Policy, Volume 43, Issue 3, 2019, Pages 262-277, ISSN 0308-5961, https://doi.org/10.1016/j.telpol.2018.07.007.

Perhaps due to challenges such as these, the introduction of new market players in the context of spectrum licensing has not always succeeded, as for example in Austria and the Czech Republic where there was no new entrant bid for the spectrum.

Situations where spectrum-based entry may be relevant

Market entry is likely to be easier in growing markets where new entrants find a "greenfield" for new customers.[233] Other aspects which influence the success of new entrants are the increasing complementarity of fixed and mobile networks. The roll-out of 5G networks requires an extensive coverage with VHCN. Network sharing (incl. national roaming) and increased access to backhaul connectivity play an important role for new entrants in mobile markets. There is also a trend to provide fixed and mobile services in a bundle. In Europe, mergers have taken place between fixed and mobile network operators (e.g. Austria, Belgium, France, and Spain). Fixed and mobile services are often sold by the same operator in major European Union economies achieving a pan-European presence (e.g. Orange, Telefonica, Deutsche Telekom, Telecom Italia, Telia-Sonera, KPN, and BT).[234]

There may also be space for new infrastructure-based entrants in specific niches. In Belgium, spectrum in the 700 MHz, 900 MHz, 1800 MHz, and 2100 MHz, as well as 3.6 GHz bands was awarded to a new entrant, a JV co-owned by B2B player, Citymesh, and B2C operator Digi Communications. With the newly acquired spectrum, the companies are cooperating on the deployment of a country-wide network that will enable Citymesh to offer a hybrid B2B mobile strategy, roaming from private to a public network and back, with Digi Communications focusing on the B2C side, including the fixed market.[235] The neutral host Dense Air has also gained spectrum in a number of countries. Neutral host business models could provide a solution to support downstream competition in areas where network duplication is not viable. Alternatively, as noted by a 2019 WIK study, [236] more extensive mobile network sharing could provide a means to limit deployment costs and support investment while maintaining competition between a larger number of MNOs at the retail level.

233 OECD (2014): "Wireless Market Structures and Network Sharing", OECD Digital Economy Papers, No. 243, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxt46dzl9r2-en (last accessed in 07.02.2023).

234 OECD (2021): Emerging Trends in Communication Market Competition, OECD Digital Economy Papers, September 2021, No. 316, https://doi.org/10.1787/4ad9d924-en (last accessed on 03.02.2023).

235 Citymesh and DIGI win spectrum in the auction and will start building a nationwide network (cegeka.com); Roemeens Digi gaat op alle fronten concurrentie aan op Belgische telecommarkt | De Tijd (googleusercontent.com).

236 WIK-Consult (2019) competition and investment in the Danish mobile market https://ens.dk/sites/ens.dk/files/Tele/final_mobile_report_denmark_clean_non-confidential.pdf

There have been claims by mobile telecom operators that investment (capex levels) and quality of service is higher for 3 player markets than for 4 player markets.[237] However, a study by Ofcom has found that investment and quality is higher in less concentrated markets, [238] while research conducted by WIK[239] found no link between consolidation or higher concentration in mobile markets and an increase in investment. These diverging findings suggest that when considering reserving spectrum for a new entrant, a case by case assessment is needed of how entry might affect investment and quality of service, taking into account conditions in the market concerned.

6.1.2 MVNO access obligations

If there are persisting competitive concerns and additional entry is not viable, or is not expected to solve the problem, another solution may be to introduce MVNO obligations or take enforcement action in relation to existing obligations relating to MVNO access, as MVNOs can, as discussed in section 5.2.3, play a role in increasing competition in mobile markets.

Many MNOs provide access to their networks to MVNOs. 7 of the 8 MNOs responding to the survey conducted for this study reported that they hosted multiple independent MVNOs or resellers, with 5 reporting that they host at least one full MVNOs. Table 6-3 shows the number of MVNO subscribers per EU Member State and their market shares as of 2018.

237 GSMA (2022a): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed on 07.02.2023).

238 Ofcom (2020b): Market Structure, investment and quality in the mobile industry, Economics Discussion Paper Series, Issue Number 1, https://www.ofcom.org.uk/__data/assets/pdf_file/0036/209799/market-structure,-investment-and-quality-in-the-mobile-industry-discussion-paper.pdf (last accessed on 07.02.2023).

239 WIK-Consult (2015) Competition & Investment: an analysis of the drivers of investment and consumer welfare in mobile telecommunications https://www.ofcom.org.uk/__data/assets/pdf_file/0029/78365/competition_and_investment_mobile.pdf

Table 6-3: MVNOs in selected EU member states (2018)

	Total mobile cellular subscriptions, 2018	MVNOs subscribers (End 2018)	Share of MVNO subscriptions over mobile subs. (%)	Number of MVNOs
Austria	16 530 441	1 200 000	7,3%	15
Belgium	11 916 735	905 764	7,6%	3
Czech Republic	13 705 387	991 286	7,2%	245
Denmark	7 197 000	…	…	1
Estonia	1 924 034	…	0,0%	1
Finland	9 530 000	…	…	0
France	93 867 215	8 614 741	9,2%	25
Germany	136 958 000	27 500 000	20,1%	5
Greece	15 354 388	62 781	0,4%	1
Hungary	11 831 338	145 380	1,23%	7
Ireland	6 282 346	589 187	9,4%	4
Italy	103 638 887	8 447 663	8,2%	19
Latvia	2 799 054	…	…	0
Lithuania	3 764 670	85 479	2,3%	4
Luxembourg	951 800	35 000	3,7%	4
Netherlands	27 087 000	4 575 000	16,9%	40
Norway	5 720 892	76 065	1,3%	3
Poland	48 285 511	2 214 507	4,6%	83
Slovak Republic	7 241 702	…	0,0%	0
Slovenia	2 465 857	74 651	3,0%	3
Spain	54 161 014	4 928 000	9,1%	12
Sweden	14 316 905	522 735	3,7%	45

Source: OECD (2021): Emerging Trends in Communication Market Competition, OECD Digital Economy Papers, September 2021, No. 316, https://doi.org/10.1787/4ad9d924-en (last accessed on 03.02.2023).

MVNO access is not generally mandated by regulation and is mostly provided based on voluntary commercial agreements. However, in some countries, regulators have introduced MVNO access obligations on the basis that MVNO access is not adequately supported by market forces alone and is necessary to support competitive service provision.

MVNO access obligations can in theory be applied through ex ante regulation (based on finding single or joint SMP in a market analysis), through obligations implemented in the spectrum licenses or as a result of obligations imposed in the context of a merger proceeding.

Regulators can impose access obligations which consist in an obligation or incentive to negotiate wholesale access or use more detailed regulatory tools which include access conditions targeted at providing equivalence of access to given technologies or at ensuring the ability of new competitors to match the pricing structure and level of established providers. From the 29 NRAs which have answered the survey on the regulatory context 9 have some form of MVNO access obligation in place.

Table 6-4: MVNO access obligations

Country	MVNO access obligation due to	Nature of obligation
Austria	Merger obligations	Access obligation (up to 16 MVNOs), reference offer, spectrum divestement, obligations expired in 2022, longer-term agreements partly in place but access conditions (pricing) for 5G are debated
Croatia	Spectrum licensing	Access obligation in all licenses, reference offer, non-discrimination
Czech Republic	Spectrum licensing	Access obligation, prices must allow equally efficient operators to profitably operate on the downstream (retail) market. Access conditions (pricing) are an issue.
France	Spectrum licensing	Access obligation (on reasonable terms), non-discrimination.
Germany	Merger commitments and negotiation order	Access obligation (30% of capacity to one of three MVNOs) in merger conditions. Access obligations expire in 2024 but national roaming agreement between 1&1 and Telefonica. Obligation to negotiate MVNO access in spectrum licence. There are issues with access conditions.
Ireland	Merger commitments	Access obligation (two MVNOs with each maximum 15% capacity), merger obligations expire in 2026.
Greece	Spectrum licensing	Obligation to negotiate, publish access conditions (excl. prices)
Norway	SMP regime and spectrum licensing conditions	access obligation, reference offer, price regulation, non-discrimination, accounting separation
Portugal	Negotiation order	Obligation to negotiate access for MVNO

Source: WIK survey.

MVNO obligations have been present in most of the markets listed for some time. In the Czech Republic, France, Germany, Greece and Portugal access obligations or obligations to negotiate access were already implemented in spectrum licences prior to

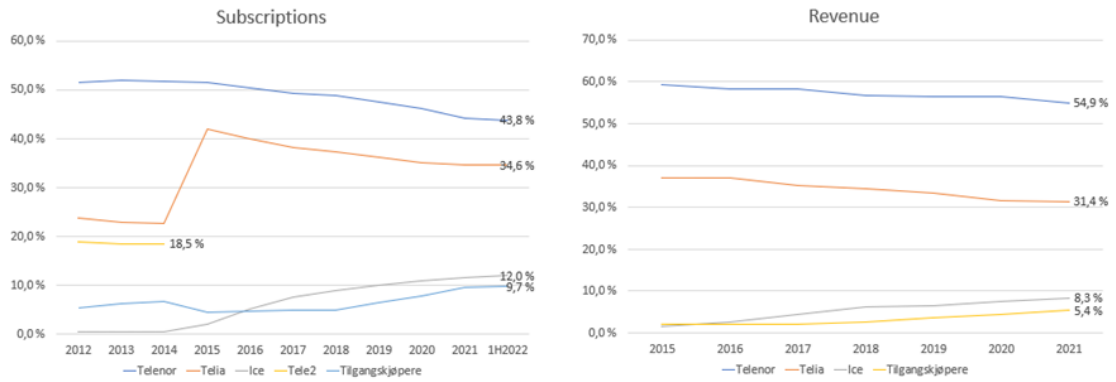
the 5G spectrum auctions, while merger-based commitments in Austria, Ireland and Germany were introduced between 2012-2014.

MVNO access obligations / investigations based on SMP

Only Norway applies an SMP based wholesale mobile access obligation. In this case, Telenor was designated with single SMP and obliged to offer wholesale access for national roaming, full MVNOs, light MVNOs (SPs) and co-location. Access should be given on non-discriminatory terms and price controls are based on prohibition for margin squeeze. The obligation is technology neutral and applies to all spectrum bands.

In justifying its SMP designation, Nkom among others noted that Telenor had a high ARPU, which was significantly above that of its competitors. Nkom also found high and relative stable market shares for Telenor, especially the share of revenues which is higher than the share of subscriptions.

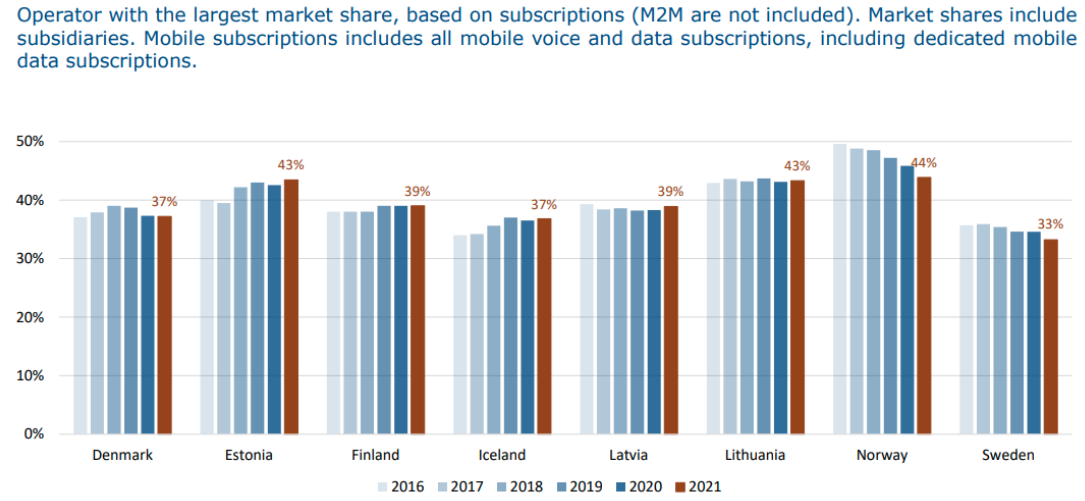
Figure 6-7: Trends in mobile market shares, Norway



Source: Nkom Statistikk

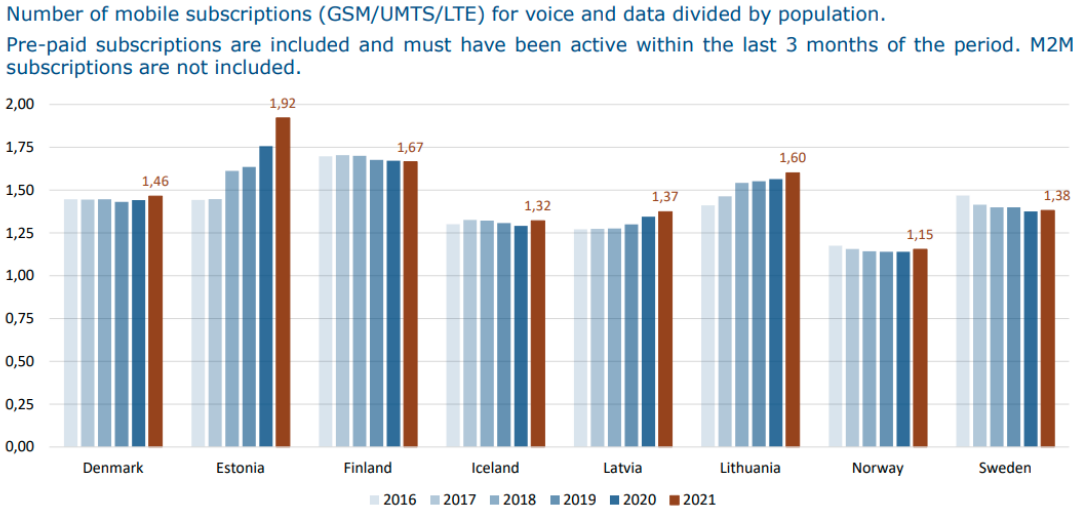
Compared to other Nordic-Baltic countries, the market share of the leading operator in Norway is higher, although it has decreased in the last years and the take-up of mobile subscriptions is lower (see figures below).

Figure 6-8: Market share of leading mobile operator



Source: Nordic-Baltic Telecom Statistic 2021, https://statistik.pts.se/media/1zijb5nm/nbs_presentation_2021.pdf

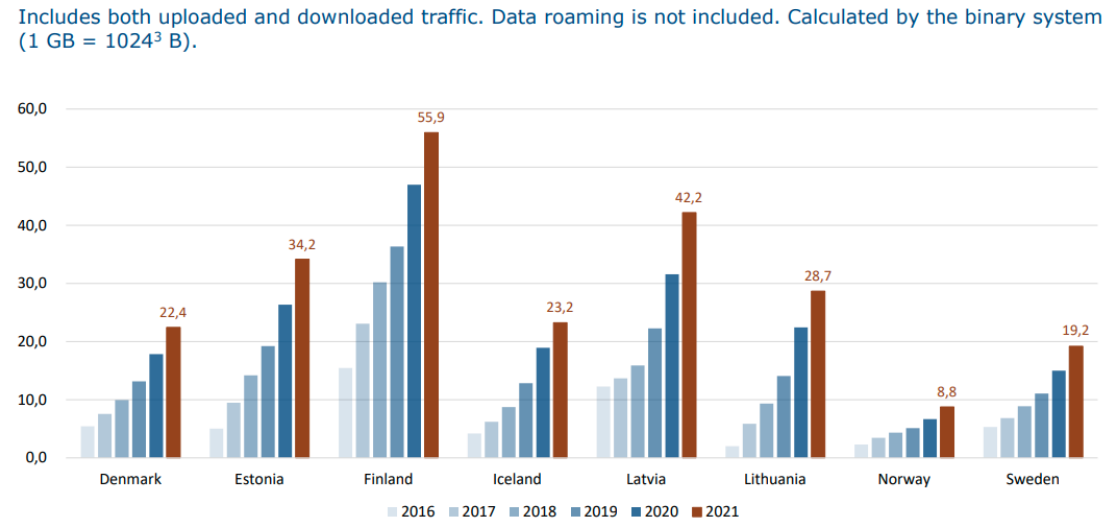
Figure 6-9: Mobile subscriptions per capita



Source: Nordic-Baltic Telecom Statistic 2021, https://statistik.pts.se/media/1zijb5nm/nbs_presentation_2021.pdf

The data transferred per capita in a month is also significantly lower in Norway than in the other comparator countries (see figure below).

Figure 6-10: Data transferred over mobile networks per capita in a month (Gbytes)



Source: Nordic-Baltic Telecom Statistic 2021, https://statistik.pts.se/media/1zijb5nm/nbs_presentation_2021.pdf

The Czech Republic notified a market analysis in which the regulator CTU found joint SMP on the mobile market. The European Commission had serious doubts as to the compatibility of the notified draft measures with Union law. In its Decision[240], the Commission observed that there was insufficient evidence that the market for wholesale access and call origination on mobile networks, as notified, met the three criteria justifying the imposition of ex ante regulation. The Commission saw clear evidence of MVNOs' presence in the market, and considered that market entry was still possible and happening, even though there might be a limited potential for growth. The Commission noted that both regulated and commercial access options were available to access seekers. All MVNOs entered the market on the basis of commercial agreements concluded with one of the three MNOs.

As the merger-based MVNO commitments in Austria will soon expire, the TKK (Telekom-Control-kommission) asked the regulator RTR to check whether a relevant market needs to be defined for sector-specific SMP regulation as part of the current market analysis cycle.

Until 2007 Market 15 "Call access and origination in public mobile telephone networks" was part of the Relevant Markets Recommendation of the European Commission and

240 European Commission (2022): COMMISSION DECISION of 17.2.2022 pursuant to Article 32(6) of Directive (EU) 2018/1972 (Withdrawal of notified draft measure), Case CZ/2021/2351: Wholesale market for access to mobile services, C(2022) 888 final, https://circabc.europa.eu/ui/group/2328c58f-1fed-4402-a6cc-0f0237699dc3/library/b9e097fb-de71-437a-9276-74628286567e/details (last accessed on 16.02.2023).

several NRAs found SMP in the market analysis. In 2006 Spain found joint dominance of the three mobile operators in a market analysis. In France, ARCEP made a similar case, but when it published this result, MNOs started to allow MVNO access to their networks and, as a result, the regulator suspended its decision.[241] In Ireland, ComReg found joint SMP for two operators. This decision was, however, annulled by the Irish Communications Appeals Panel. Since market 15 was removed from the list of relevant markets in 2007,[242] in principle, NRAs still can analyse mobile markets and find single or joint SMP but must in addition to finding SMP, demonstrate that the market passes the three criteria test.[243] MVNO access obligations under SMP regulation generally require a market analysis and finding of "joint SMP". This concept has been further elaborated in the context of the SMP Guidelines,[244] but no cases have been confirmed in recent years.[245]

MVNO access obligations based on mergers[246]

In three countries (Austria, Germany and Ireland) MVNO access obligations have been introduced in the context of a merger commitment as the European Commission (DG Competition) was concerned about the impact of a reduction of the number of MNOs on competition.[247]

In the Austrian case the Commission considered that the merger would likely lead to a significant impediment to effective competition on the basis of non-coordinated effects on the market for mobile telecommunications service to end customers in Austria. The Commission explained that "H3G was an important, if not the most important, competitive

241 OECD (2014): Wireless Market Structures and Network Sharing, OECD Digital Economy Papers, No. 243, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxt46dzl9r2-en (last accessed on 24.03.2023).
242 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007H0879
243 Article 67 EECC
244 Communication from the Commission — Guidelines on market analysis and the assessment of significant market power under the EU regulatory framework for electronic communications networks and services https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018XC0507%2801%29 (last accessed on 24.03.2023).
245 Dutch NRA ACM found that KPN and VodafoneZiggo had joint SMP in the wholesale fixed access market and its draft Decision was approved by the EC, but later annulled on appeal https://www.vodafoneziggo.nl/en/nieuws/court-accepted-appeal-vodafoneziggo/
246 The text in this section draws on a 2021 study by WIK-Consult "The role of MVNOs in evolving mobile markets" https://www.comreg.ie/?dlm_download=the-role-of-mvnos-in-evolving-mobile-markets-report-by-wik-consult-2
247 European Commission (2013): Final Report of the Hearing Officer (1) Hutchinson 3G Austria/Orange Austria (COMP/M.6497) (2013/C 224/05), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2013:224:FULL&from=EN; European Commission (2014): Case No COMP/M.6992 HUTCHISON 3G UK / TELEFONICA IRELAND, https://ec.europa.eu/competition/mergers/cases/decisions/m6992_20140528_20600_4004267_EN.pdf and European Commission (2014): CASE M.7018 - TELEFÓNICA DEUTSCHLAND/ E-PLUS, MERGER PROCEDURE REGULATION (EC) 139/2004, https://ec.europa.eu/competition/mergers/cases/decisions/m7018_6053_3.pdf (last accessed on 24.03.2023).

force in the market and that its incentive to remain a driving force, in the absence of substantiated efficiencies, would be reduced after the transaction".[248]

In the German case the Commission reached the conclusion that the "proposed transaction would give rise to non-coordinated anti-competitive effects because it involves the elimination of important competitive constraints that the merging parties previously exerted upon each other together with a reduction of competitive pressure on the remaining competitors in an already highly concentrated market."[249] The Commission did not expect that these anti-competitive effects would be offset by countervailing factors such as possible buyer power, entry and efficiencies.

In the Irish case the Commission concluded that the merger would remove an important competitive force because it reduced the number of MNOs from four to three and would eliminate the (at the time) existing competition between the merging parties, providing the merged entity with an incentive to increase price.[250]

The conditions imposed by the European Commission on the merger between H3A and Orange in Austria in December 2012 included an:

1. Obligation to **grant access** to an MVNO at the time of the merger on the basis of a **reference offer** approved by the European Commission.
2. Obligation to **provide access to up to 16 MVNOs** on the basis of the same reference offer. The upper limit of the obligation is 30% of H3A's network capacity and is limited to 10 years.
3. Obligation to **divest frequencies** to supplement the frequencies reserved for new entrants in the multi-band frequency auction in 2013.[251]

The availability of a Reference Offer specified at a high level of detail is a key distinction between the remedies pursued in Austria compared with the remedies applied in Ireland and Germany (discussed below). The H3G Reference Offer specifies inter alia that:

248 European Commission (2012): Case No COMP/M.6497 – HUTCHISON 3G AUSTRIA / ORANGE AUSTRIAREGULATION (EC) No 139/2004 MERGER PROCEDURE, https://ec.europa.eu/competition/mergers/cases/decisions/m6497_20121212_20600_3210969_EN.pdf (last accessed on 13.02.2023).

249 European Commission (2014a): CASE M.7018 - TELEFÓNICA DEUTSCHLAND/ E-PLUS, MERGER PROCEDURE REGULATION (EC) 139/2004, https://ec.europa.eu/competition/mergers/cases/decisions/m7018_6053_3.pdf (last accessed on 14.02.2023).

250 European Commission (2014b): Case No COMP/M.6992 HUTCHISON 3G UK / TELEFONICA IRELAND, MERGER PROCEDURE REGULATION (EC) 139/2004, https://ec.europa.eu/competition/mergers/cases/decisions/m6992_20140528_20600_4004267_EN.pdf (last accessed on 14.02.2023).

251 See European Commission (2012): Case M.6497 Hutchison 3G Austria Holdings GmbH, Commit-ments to the European Commission, 11 November 2012, p. 113 ff., https://ec.europa.eu/competition/mergers/cases/decisions/m6497_20121212_20600_3210969_EN.pdf (last accessed on 24.03.2023).

- Wholesale access services are provided using the same technology that H3G uses to provide services to its customers. Developments of new mobile technologies and/or new products that are realized over existing technologies must be made available to the MVNO within a reasonable period of time and within a specified time frame after H3G has launched the service.[252]
- H3G offers a diverse range of pricing models, including per-unit charges for circuit-switched services, SMS and packet-switched data services (with a choice between a fixed per-unit charge or volume-based charges for packet-switched data services), revenue-based discounts and a -25% retail-minus option for SIM-only data tariffs.[253]
- The prices are subject to retail price indexing, which is to be agreed upon individually.[254] The set-up fee for MVNO access is a maximum of €200,000. H3G is subject to a non-discrimination obligation.[255] H3G shall offer a contract for a period of up to 10 years.

If the parties cannot agree on the terms of the MVNO agreement within 5 months, the matter can be referred to an independent dispute resolution body.

In contrast to the public Reference Offer approach applied in Austria, in Germany, the remedies applied by the Commission in July 2014 aimed to secure commitments for a strong form of MVNO access with a more limited number of players. The merged entity (TEF/ePlus) was required to sell up to 30% of its network capacity of the merged entity to one to three MVNOs, which were termed Upfront Mobile Bitstream Access MVNOs (MBA MVNOs). Under the arrangement the upfront MBA MVNO(s) would pay a fixed price for access to specific capacity on the merged entity's consolidated network in addition to a usage-based tariff for voice, data and SMS. In combination, this pricing model was designed to create incentives for MVNO's growth and to split the risk between the merged company and its MBA MVNO partner. However, the specification of remedies in Germany was less detailed than in Austria, which resulted in disputes between the parties and TEF. TEF also committed to continuing existing wholesale contracts with the

252 See European Commission (2012): CASE COMP M.6497 H3G / ORANGE COMMITMENTS TO THE EUROPEAN COMMISSION 11 NOVEMBER 2012, p. 18, https://www.drei.at/media/common/pdf/info/wholesale/2012h3greferenceoffer.pdf. (last accessed on 24.03.2023).

253 See European Commission (2012): CASE COMP M.6497 H3G / ORANGE COMMITMENTS TO THE EUROPEAN COMMISSION 11 NOVEMBER 2012, p. 31 f., https://www.drei.at/media/common/pdf/info/wholesale/2012h3greferenceoffer.pdf, https://www.drei.at/media/common/pdf/info/wholesale/zusammenfassung-deutsch.pdf. (last accessed on 24.03.2023).

254 See European Commission (2012): CASE COMP M.6497 H3G / ORANGE COMMITMENTS TO THE EUROPEAN COMMISSION 11 NOVEMBER 2012, p. 20, https://www.drei.at/media/common/pdf/info/wholesale/2012h3greferenceoffer.pdf. (last accessed on 24.03.2023).

255 See European Commission (2012): CASE COMP M.6497 H3G / ORANGE COMMITMENTS TO THE EUROPEAN COMMISSION 11 NOVEMBER 2012, p. 21, https://www.drei.at/media/common/pdf/info/wholesale/2012h3greferenceoffer.pdf (last accessed on 24.03.2023).

TEF and E-Plus contractors until 2025, and to grant MVNOs on their network access to 4G (LTE).[256] However, unlike in Austria, MVNOs other than those benefiting from capacity-based agreements did not have access on the basis of regulated conditions.

In May 2014, the European Commission approved the merger between Three Ireland and Telefonica, leaving 3 MNOs, with Eir and Vodafone as the other operators. The remedies adopted as a condition of the approval of the merger in Ireland were in some ways similar to those in Germany, and focused on the entry of two MVNOs with an option for one of them to become a full mobile network operator by acquiring spectrum at a later stage.[257] As in Germany, these MVNO agreements were required to be based on a "capacity-based" MVNO model, whereby the two new entrants could obtain a dedicated pipe for voice and data traffic.[258] The maximum capacity allocation for the two MVNO providers was set at 15% of the merged company's network capacity for each of the MVNOs.

In Austria the merger commitments expired in December 2022, while in Ireland they will expire in January 2026. In Germany the merger commitment will expire in 2024. 1&1 reached an agreement on national roaming with Telefonica after acquiring a spectrum license in 2019, however, there are issues related to access conditions.[259]

MVNO obligations based on spectrum licenses

Another mechanism under which MVNO access can be introduced is to attach MVNO obligations as a condition for the award of spectrum licences. This was possible under the EU electronic communications framework, under provisions in the 2002 Authorisation Directive (Annex B point 7),[260] which provides that conditions which may be attached to rights of use for radio frequencies may include "Any commitments which the undertaking obtaining the usage right has made in the course of a competitive or comparative selection procedure".

256 See European Commission (2014): COMMISSION DECISION of 2.7.2014 addressed to: Telefónica Deutschland Holding AG declaring a concentration to be compatible with the internal market and the EEA agreement (Case M.7018 - TEF DEUTSCHLAND/ E-PLUS), http://ec.europa.eu/competition/mergers/cases/decisions/m7018_6053_3.pdf.

257 See https://ec.europa.eu/commission/presscorner/detail/en/IP_14_607.

258 Para 52, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=uriserv:OJ.C_.2014.264.01.0006.01.ENG.

259 See responses to consultation on the BNetzA position paper on the assignment of spectrum in the 800 MHz, 1,800 MHz and 2,600 MHz bands, for example Hengeler Mueller (2022): Rechtsgutachten Wettbewerbsförderung durch die Diensteanbieterverpflichtung Stellungnahme zum Positionspapier der Bundesnetzagentur erstellt für die freenet AG, https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/OeffentlicheNetze/Mobilfunknetze/mobilfunknetze-node.html (last accessed on 17.02.2023).

260 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002L0020

The 2018 EU Electronic Communications Code, which was due to enter into force in December 2020, contains a similar provision[261] noting that conditions which may be attached to rights of use for radio spectrum can include "Any commitments which the undertaking obtaining the rights of use has made in the framework of an authorisation or authorisation renewal process prior to the authorisation being granted or, where applicable, to the invitation for application for rights of use". However, MVNO access conditions would also need to comply with more stringent conditions set out in Article 52 EECC which enables MS to take certain measures in the context of awarding spectrum licences in order to promote "effective competition". Specifically, under Art 52, MS may:

> *"limit the amount of radio spectrum bands for which rights of use are granted to any undertaking, or, in justified circumstances, attach conditions to such rights of use, such as the provision of wholesale access, national or regional roaming, in certain bands or in certain groups of bands with similar characteristics";*

National regulatory and other competent authorities shall, taking into account market conditions and available benchmarks, base their decisions on an objective and forward-looking assessment of the market competitive conditions, of whether such measures are necessary to maintain or achieve effective competition, and of the likely effects of such measures on existing and future investments by market participants in particular for network roll-out. In doing so, they shall take into account the approach to market analysis as set out in Article 67(2).

In 2019, the German regulatory authority BNetzA introduced an obligation that the four 5G spectrum licensees for 2 GHz and 3,6 GHz spectrum bands should negotiate with suitable service providers on the shared use of frequencies.[262] The negotiations must be non-discriminatory and the capacities to be provided should not be limited to specific services, radio technologies or applications. There is no obligation for the licensees to

261 EU Electronic Communications Code Annex 1, D point 7

262 BNetzA (2019a): Entscheidung der Präsidentenkammer vom 14. Mai 2018 über Anordnung und Wahl des Verfahrens zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz für den drahtlosen Netzzugang – Aktenzeichen: BK1-17/001 – https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/20180514_Auktion2019Entscheidungen_I_II.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=5 (last accessed on 24.03.2023).
BNetzA (2019b): Konsultationsentwurf einer Entscheidung der Präsidentenkammer der Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen über die Festlegungen und Regeln im Einzelnen (Vergaberegeln) und über die Festlegungen und Regelungen für die Durchführung des Verfahrens (Auktionsregeln) zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz. - Aktenzeichen: BK1-17/001 - https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/Auktion2019Entscheidungsentwurf_III_IV_pdf.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=2 (last accessed on 24.03.2023).

reach an agreement for the provision of MVNO access. However, the Federal Network Agency has the power to intervene to protect competition, i.e. to act as an "arbitrator".”[263]

As justification for this obligation, in its consultation document and the following decision in 2019 the BNetzA explained that “since the beginning of liberalisation in the early 1990s, service providers have contributed to strengthening competition at service level and thus to promoting consumer interests. The MVNO access obligation imposed in 2000, which has its basis in the licensing obligations of the 1990s, ends on 31 December 2020. The Presidential Chamber therefore sees a need for action to maintain and promote competition at the service level.” There has been a dispute resolution procedure concerning the negotiation of MVNO access between Transatel and Telefonica with the result that Telefonica was requested to enter into negotiations with Transatel after it failed to obtain access to 5G services.[264]

At the end of 2022 BNetzA consulted on the assignment of frequencies in the 800 MHz, 1,800 MHz and 2,600 MHz frequency bands. The consultation procedure on the position paper from 2022 was open until 21 November 2022. The negotiation of MVNO access obligation was part of the consultation and in its response to consultation the Competition

263 BNetzA (2019a): Entscheidung der Präsidentenkammer vom 14. Mai 2018 über Anordnung und Wahl des Verfahrens zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz für den drahtlosen Netzzugang – Aktenzeichen: BK1-17/001 – https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/20180514_Auktion2019Entscheidungen_I_II.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=5 (last accessed on 24.03.2023).
BNetzA (2019b): Konsultationsentwurf einer Entscheidung der Präsidentenkammer der Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen über die Festlegungen und Regeln im Einzelnen (Vergaberegeln) und über die Festlegungen und Regelungen für die Durchführung des Verfahrens (Auktionsregeln) zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz. - Aktenzeichen: BK1-17/001 - https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/Auktion2019Entscheidungsentwurf_III_IV_pdf.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=2 (last accessed on 24.03.2023).

264 Bundesnetzagentur (2021): Beschluss in dem Verwaltungsverfahren aufgrund des Antrages der Transatel SAS, 49-51 Quai de Dion Bouton, 92806 Puteaux, Frankreich, vertreten durch die Geschäftsführung, - Antragstellerin - gegen Telefónica Germany GmbH & Co. OHG, Georg-Brauchle-Ring 50 80992 München,Deutschland, vertreten durch die Geschäftsführung, – Antragsgegnerin – wegen Streitbeilegung betreffend Verhandlungspflicht über einen MVNO-Zugang, BK2b-21/005, https://www.bundesnetzagentur.de/DE/Beschlusskammern/1_GZ/BK2-GZ/2021/BK2-21-0005/BK2-21-0005_Beschluss_download_BF.pdf?__blob=publicationFile&v=3 (last access on 17.01.2023) and Freenet (2022): Stellungnahme der freenet AG zum Positionspapier der Bundesnetzagentur zur Bereitstellung von Frequenzen in den Bereich 800 MHz, 1.800 MHz und 2.600 MHz für den Ausbau digitaler Infrastrukturen, https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/OeffentlicheNetze/Mobilfunknetze/mobilfunknetze-node.html (last accessed on 17.02.2023).

Authority expressed doubts whether the negotiation obligation alone is effective in ensuring MVNO access.[265]

In Portugal, the Regulation of the 2020 multiband auction (5G Auction)[266] also included the obligation to negotiate access for MVNO and national roaming. MEO, NOS and VODAFONE, as current MNO and winners of 2 x 10 MHz in the 700 MHz (in case of the latter two) or at least 50 MHz in the 3,6 GHz band (in case of MEO), are obliged to comply with this requirement, as is DENSE AIR following the amendment and reissue of its right of use of frequencies approved by decision of November 4th 2020.The beneficiaries of the national roaming obligation in Portugal are the new entrants, NOWO and Dixarobil, who acquired rights of use both in the main and the new entrants' bidding phase,[267] while the obligation to negotiate for MVNO access applies more widely.

The entities subject to the network access obligation have to negotiate in good faith with the beneficiaries to reach commercial agreements for either MVNO or national roaming. In the event that the parties don't reach an agreement within the deadline established in the auction Regulation, either party may require ANACOM's intervention. For either MVNO and national roaming the host networks are required to provide conditions which allow the provision of services equivalent to the ones provided by the host networks to their own retail clients.

In the consultation document on the designation of the 700 MHz for electronic communications services, later reinforced in the report on the consultation procedure, ANACOM argued about the importance of promoting competition in the Portuguese market, mainly by creating conditions that would allow new entrants in the market, and in this regard included national roaming and MVNO access obligations in the spectrum licenses. Among others, a growing convergence of operations carried out by the three

265 See Bundeskartellamt (2022): Positionspapier 2022, hier: Stellungnahme des Bundeskartellamtes, B7-401/15, https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Stellungnahmen/Stellungnahme_Frequenzvergabe_BNetzA_2018.pdf?__blob=publicationFile&v=3 (last accessed on 13.02.2023)

266 ANACOM (2020): Regulamento n.º 987-A/2020, Regulamento do Leilão para a Atribuição de Direitos de Utilização de Frequências nas faixas dos 700 MHz, 900 MHz, 1800 MHz, 2,1 GHz, 2,6 GHz e 3,6 GHz, https://www.anacom.pt/render.jsp?contentId=1703983 (last accessed on 23.12.2022), ANACOM (2021): Regulamento n.º 596-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, https://files.dre.pt/2s/2021/06/125000001/0000200004.pdf; ANACOM (2021): Regulamento n.º 867-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, alterado pelo Regulamento n.º 596-A/2021, de 30 de junho, https://files.dre.pt/2s/2021/09/183000001/0000300006.pdf (last accessed on 23.12.2022).

267 ANACOM (2020): Regulamento n.º 987-A/2020, Regulamento do Leilão para a Atribuição de Direitos de Utilização de Frequências nas faixas dos 700 MHz, 900 MHz, 1800 MHz, 2,1 GHz, 2,6 GHz e 3,6 GHz, https://www.anacom.pt/render.jsp?contentId=1703983 (last accessed on 23.12.2022), ANACOM (2021): Regulamento n.º 596-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, https://files.dre.pt/2s/2021/06/125000001/0000200004.pdf; ANACOM (2021): Regulamento n.º 867-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, alterado pelo Regulamento n.º 596-A/2021, de 30 de junho, https://files.dre.pt/2s/2021/09/183000001/0000300006.pdf (last accessed on 23.12.2022).

largest operators in the market, notorious in terms of stable market shares of MNOs and the high price level (several international benchmarks were referenced) were indicated as reasons for reserving spectrum for a new entrant and the national roaming and MVNO access obligation in the licenses. They also refer to the statement of the competition authority which supports the decision to impose an MVNO access obligation and considers spectrum as an essential input for market entry and sustainable competition. Both ANACOM and the Competition Authority (AdC) refer to the competition conditions on the mobile market (and also to the relevance for fixed broadband access).[268]

In Croatia, an MVNO obligation was included for all radio frequency spectrum license holders at the national level in the public auction procedure in 2021, regardless of whether they are new operators or historical operators who already have a license for use of the radio spectrum. Licensees at the national level are obliged to negotiate in good faith with all parties interested in offering services on the market as an MVNO operator and, in case of a reasonable request, to prepare appropriate wholesale conditions within a period of 3 months from the acceptance of a reasonable request. Appropriate wholesale conditions must be prepared in the form of a Reference Offer for network access to mobile virtual network operators. In the Croatian mobile market in 2019 three MNOs were active and two of them sold services under sub-brands but no full or light MVNOs were present in the market.[269]

In the Czech Republic, based on frequency auctions in 2013 in bands 800 MHz, 1800 MHz and 2600 MHz (hereafter “LTE auction”) and in 2020 in bands 700 MHz and 3400–3600 MHz (hereafter “5G auction”) MNOs have commitments to provide access to MVNOs to services operated on frequencies gained in those two auctions. Prices for such access should be set in a way that allows to equally efficient operators to profitably operate on the downstream (retail) market. As a complement to these requirements, the CTU publishes a study on market development each year and in case of disputes issues opinions regarding MVNO access, although these are non-binding.

In France, MNOs have an obligation in their spectrum licences to offer wholesale access to any MVNOs seeking access on reasonable terms. In return, the MNO wholesale access must be granted on reasonable conditions. The most recent obligation, written in the 3,5 GHz licences, obliges MNOs to grant access to their whole network, i.e. independent of the spectrum band (the obligation is the same for all 4 MNOs). The reasonable terms are assessed based on the services provided by both parties and their

268 https://www.anacom.pt/streaming/RelatorioLeilo30102020VPublica.pdf?contentId=1567541&field=ATTACHED_FILE and https://www.anacom.pt/streaming/OutrasEntidades_parte1.pdf?contentId=1567665&field=ATTACHED_FILE

269 Worldbank (2021): Assessment of the Digital Market in Croatia, Final Report, https://openknowledge.worldbank.org/handle/10986/35541 (last accessed on 16.02.2023).

respective contribution to the launch and the running of the MVNO's services. The wholesale prices result from a negotiation between the parties, ARCEP does not regulate wholesale mobile access prices. As justification for the intervention, in its decision on the licensing of 3,4-3,8 GHz frequency bands, ARCEP[270] makes reference to the telecommunications law which provides that "the Regulatory Authority for Electronic Communications, Posts and Press Distribution shall take reasonable and proportionate measures, under objective and transparent conditions, to achieve the following objectives: 1° The exercise, for the benefit of users, of effective and fair competition between network operators and providers of electronic communications services [...][271] It is understood that ARCEP has sought information and actively monitors MVNO access conditions based on this licence obligation. When issues were raised regarding MVNO access, ARCEP notes that it was possible to address these through informal dialogue, and that there have been no formal disputes on MVNO access for more than 10 years.[272]

A negotiation order also applies in Greece where obligations apply to mobile networks irrespective of the spectrum band. If there is no agreement, a dispute resolution mechanism can be activated with the NRA determining terms and conditions for providing access and interconnection of services.

Circumstances in which MVNO obligations have been applied

When looking at the countries in which MVNO obligations have been applied and were in force at least in relation to 4G networks (see Table 6-5), it is notable that with one exception (France), they have been applied in countries which had 3 established MNOs at the time the obligations were applied, or were subject to mergers which reduced the number of operators to 3. In Germany and Portugal, spectrum has recently been awarded to a 4th entrant, but the new MNOs are still in the process of deploying their networks, and the prospects for infrastructure-based competition were still uncertain at the time when MVNO obligations were imposed.

In cases where MVNO obligations have been applied in the context of spectrum licence awards, these obligations were imposed under the 2002 Authorisation Directive as

270 Décision n° 2019-1386 de l'Autorité de régulation des communications électroniques, des postes et de la distribution de la presse en date du 21 novembre 2019 proposant au ministre chargé des communications électroniques les modalités et les conditions d'attribution d'autorisations d'utilisation de fréquences dans la bande 3,4 - 3,8 GHz en France métropolitaine pour établir et exploiter un réseau radioélectrique mobile ouvert au public, https://www.arcep.fr/uploads/tx_gsavis/19-1386.pdf

271 L'article L. 32-1 du CPCE dispose que : « l'Autorité de régulation des communications électroniques, des postes et de la distribution de la presse prend, dans des conditions objectives et transparentes, des mesures raisonnables et proportionnées en vue d'atteindre les objectifs suivants : 1° L'exercice au bénéfice des utilisateurs d'une concurrence effective et loyale entre les exploitants de réseau et les fournisseurs de services de communications électroniques […] ».

272 Information from interview.

amended in 2009.[273] Thus, there is as yet no experience in the application of Article 52 EECC in the context of spectrum-based MVNO obligations. If and when this provision is applied, it will likely require additional analysis of the competitive dynamics in the market and implications of MVNO obligations for competitive development and network investment compared with the relatively brief justifications given for the inclusion of MVNO obligations in spectrum awards in the past. The requirement for justification based on competitive conditions may require a form of market analysis, which takes into account the principles used in the context of imposing obligations based on SMP. In assessing the impact of any such obligations on investment, it may be relevant however to take into account that the eventual cost of spectrum when awarded through an auction procedure for example, would normally reflect any direct or indirect cost (e.g. related to possible reductions in retail market share) linked to MVNO obligations, while investment levels may be affected more by commitments relating to coverage and/or quality of service levels, the degree of infrastructure competition and the scope to make use of network sharing than by obligations relating to MVNO access, which is often provided on a voluntary basis in markets with strong competitive dynamics.

Most countries without MVNO obligations have or have sought to promote a market structure involving at least 4 MNOs. In NL there were 4 players prior to the exit of Tele2 in 2019,[274] while in Belgium, the authorities have pursued a policy of encourage the entry of a fourth player although marketing by the 5G-based 4th entrant Digi may not begin until 2024.[275]

Outcomes: presence of MVNOs on the market

The following chart shows the market shares of MVNOs based on responses by NRAs to an online survey distributed in November 2022 as well as other sources. The countries with MVNO obligations are shown on the left, with the strongest form of regulation (SMP wholesale access regulation) to the far left, followed by countries which feature merger-based MVNO access commitments, and then countries with MVNO obligations which are included in spectrum licences, most of which require MNOs to negotiate access while not explicitly mandating it.

MVNOs do play a role in the markets which feature stronger (SMP or merger-based) MVNO access regulation, but it is notable that they also play a role in other countries such as Italy, the Netherlands, Belgium and Denmark, which do not feature MVNO

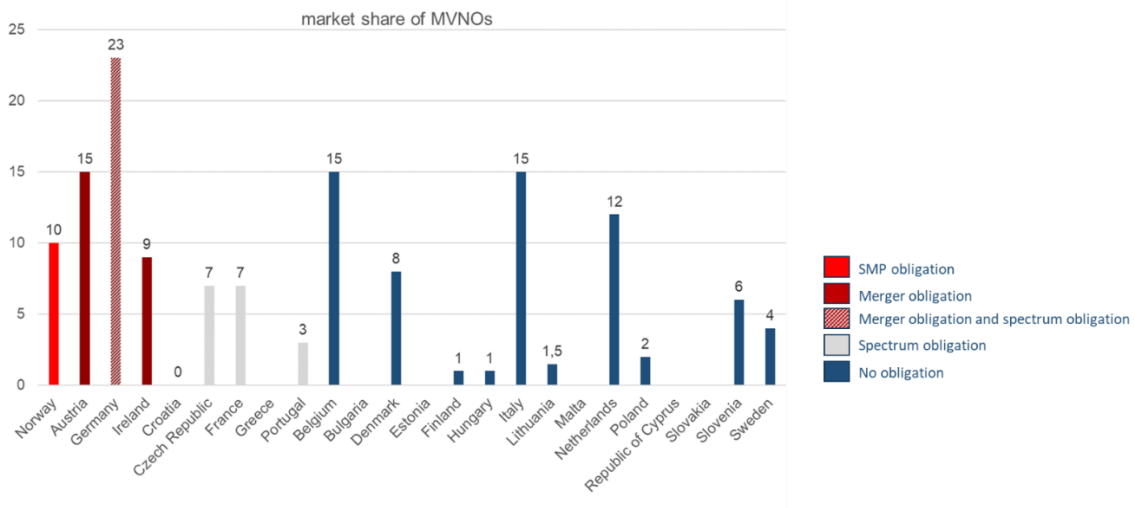
273 Most awards occurred before the EU Electronic Communications Code entered into force in December 2020. In Croatia, the award occurred in 2021, but the EECC had not been transposed at the time when the spectrum licences were issued.

274 In the Netherlands: Ziggo (Liberty Global) entered the market in May 2012, and then merged Q4 2016; with Vodafone; Tele2 entered the market January 2015 merging in Q1 2019 with T-Mobile; at present there are only three MNOs.

275 https://www.tijd.be/ondernemen/telecom/nieuwe-operator-digi-begint-mogelijk-pas-in-2024-in-belgie/10407258.html (last accessed on 27.03.2023).

access regulation. It is not clear to what extent (typically lighter) spectrum-based MVNO obligations have supported the expansion of MVNOs in those countries where it applies. The effect may be linked to the date of introduction and nature of the obligations and involvement of the NRA in formally or informally resolving disputes, as well as wider market dynamics including the willingness of MNOs to engage in hosting MVNOs. MVNOs play a significant role in Germany (which has long-standing spectrum licence based obligations to negotiate, alongside the merger commitments which applied to only one player). However, MVNOs play a smaller role in the Czech Republic, despite the NRA's efforts to monitor the market and provide informal guidance, and an even more limited role in Greece and Portugal, despite the longstanding inclusion of MVNO negotiation obligations in spectrum licences. In France, the role of consumer MVNOs is limited by the strong competitive dynamic amongst MNOs, while in Croatia the effect of recently introduced MVNO access obligations is yet to be observed.

Figure 6-11: Market shares of MVNOs[276]



Source: WIK survey and other sources.[277] Data for Denmark and Lithuania refers to 2019. Please note that in Germany and Portugal the 4th MNO is a new entrant which has recently acquired spectrum the market. In Belgium the European Commission agreed to the take-over of Base by Telenet in 2016 under the condition that the subscriber base of Mobile Vikings (which was in part held by Base) was

276 Red indicates SMP-based MVNO obligations, burgundy merger-based obligations, grey spectrum-based obligations. Countries with no MVNO obligations are marked in blue.

277 Survey data and https://www.agcom.it/osservatorio-sulle-comunicazioni (Italy), Godlovitch, I.; Lucidi, S. and Sörries, B. (2019): Competition and investment in the Danish mobile market, https://ens.dk/sites/ens.dk/files/Tele/final_mobile_report_denmark_clean_non-confidential.pdf, RRT (2020): LITHUANIAN COMMUNICATIONS SECTOR 2019, https://www.rrt.lt/wp-content/uploads/2020/09/Lithuanian-communications-sector-2019.pdf (last accessed on 10.02.2023), ARCEP (2023): SERVICES MOBILES 4E TRIMESTRE 2022 OBSERVATOIRE DES MARCHES DES COMMUNICATIONS ELECTRONIQUES, https://www.arcep.fr/fileadmin/cru-1676044269/reprise/observatoire/obs-mobile/2022/t4-2022/obs-mobile-t4-2022_090223.pdf (last accessed on 10.02.2023).

transferred to Medialaan (today DPG).[278] In 2021, the Belgian competition authority approved the acquisition of Mobile Vikings by MNO Proximus.[279]

Although their market shares may not be significant in relation to the number of subscriptions at national level[280] it is also important to consider the ability for IoT specialists to offer services across the EU. These players typically use a mix of MVNO access and roaming to provide connectivity. Respondents to the survey included specialist business / IoT MVNOs in Germany and France. It is not clear to what extent MVNO agreements have been signed for this type of service provider in other countries. In order to track market dynamics in this area, it may be useful to gather data at EU level on market shares in SIM cards / eSIM profiles used for M2M, and identify in this context the proportion of subscriptions that are supplied by MVNOs.

Effects on choice, price and quality

The following table provides an overview of possible input factors which could influence market outcomes such as the number of MNOs and presence of MVNO obligations alongside key outcome indicators including prices for low and high usage data baskets and average download speeds.

278 BIPT (2021): Communication du Conseil de l'IBPT du 4 mai 2021 concernant l'impact d'un quatrième opérateur de réseau mobile sur le marché mobile belge, https://www.ibpt.be/file/cc73d96153bbd5448a56f19d925d05b1379c7f21/e6c9b38108e2129e8aeb7361c775d717f66c0ff6/communication_impact_quatrieme_operateur_reseau_mobile_belgique.pdf (last accessed.on 10.02.2023).

279 21-CC-10 Proximus NV / Mobile Vikings NV | Autorité belge de la Concurrence (abc-bma.be) (last accessed on 24.03.2023).

280 Business focused and IoT MVNOs responding to the survey generally reported market shares of below 2%.

Table 6-5: Overview over MVNO access and outcomes[281]

	Country size	No. MNOs	MVNO obligations	Market share MVNOs	Price (low cost)	Price (high data)	Mobile data usage (GB per month)	Average download speeds (Mbit/s)	
AT	Small-Mid	3	Merger	**15%**	9.04	19.37	26.365	63.05	12.77
CZ	Mid	3	Spectrum	7%	30.65	44.68	4.635	41.3	13.72
FR	Large	4	Spectrum	7%	13.33	14.2	11.166	63.68	7.51
DE	Large	3*	Merger + Spectrum	**23%**	9.63	25.73	6.02	58.83	11.52
IE	Small	3	Merger	9%	9.67	9.67	9.098	26.54	8.08
NO	Small	3	SMP + spectrum	10%	13.97	38.74	9.523	128.14	18.27
PT	Mid	3*	Spectrum	2%	11.99	34.96	5.856	59.23	12.19
IT	Large	4	None	**25%**	11.67	12.39	12.577	42.68	9.49
DK	Small	4	None	11%	16.27	16.27	16.082	119.55	19.45
BE	Mid	3	None	**15%**	12.67	28.11	4.098	56.46	11.18
SE	Mid	4	None	4%	7.78	19.56	15.268	89.84	15.2
SI	Small	4	None	6%	6.08	20.08	10.703	51.8	9.58
NL	Mid	3	None	12%	9.99	15.85	4.696	112.15	16.75
HU	Mid	4	None	1%	27.55	55.14	9.136	43.38	14.35
PL	Large	5	None	2%	9.49	11.38	10.844	40.35	9

Source: WIK.

In the countries where MVNO obligations have been applied, market outcomes in terms of price and quality in mass-market mobile services are mixed. A detailed analyses of the specific conditions within the markets concerned as well as the nature and strength of the obligations imposed is needed to understand what lies behind these outcomes.

The MVNO landscape in Norway is noteworthy as it is the only country where SMP regulation on the incumbent is in place. This has led to MVNOs being able to offer

281 When comparing mobile prices in an international benchmark some methodological issues should be taken into account. The mobile prices shown below cover at least the two largest mobile network operators (based on subscriptions) of the countries in question, but do not include MVNOs. They are calculated based on the least expensive offers per basket and respective operator at a given point in time. Discounts can complicate the analysis and comparability of the data, in particular over time. The same applies for additional features, which are not considered in the benchmark analysis (e.g. zero rating options). Also, in light of deviations in the demand patterns the baskets chosen may be more relevant (in terms of market shares) in some countries and play a less important role in others. in particular, the baskets surveyed tend to be oriented towards the lower end of demand. Accordingly, in advanced countries, products with higher inclusion volumes must sometimes be taken into account for the comparison if the selected baskets are no longer served.

contracts more cheaply than the incumbent[282] as well as enabling them to include 5G offers directly from the start without any further renegotiations or significant time lag. According to interviews for this study, MVNOs are also able to offer competitive packages for business customers due to the regulation in Norway, which is not the case in all countries. Prices in Norway for higher volume offers are relatively high, but the network quality is also the highest amongst the countries considered. Another possible reason[283] for higher MNO prices in the high value segment may be the (potentially inaccurate) perception by consumers that quality of service offered by MVNOs is lower than that of network operators, thereby weakening the competitive pressure exerted by MVNOs.

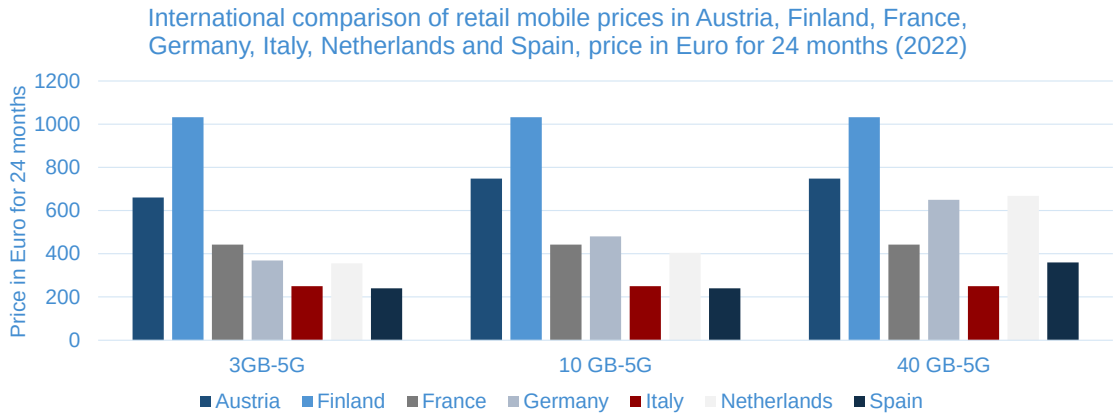
MVNO access obligations resulting from commitments in the context of 4 to 3 mergers in Europe have also played a role in supporting positive outcomes for consumers, but with mixed results, which may be due in part to the fact that the MVNO access terms resulting from the commitments were limited in Germany and Ireland to specific stakeholders selected with the involvement of the merging parties, while in Austria, which achieved more positive results, the obligation to provide MVNO access was specified in more detail and was open to a wider number of parties.[284]

The introduction of a Reference Offer as a result of merger commitments in Austria[285] coincided with[286] the entry of price-aggressive MVNO HoT (Hofer) which triggered declining price levels from the other operators.[287] It is notable in this case that the mass-market MVNOs HoT and spusu were able to offer high data volume bundles competitively based on the 4G network. This is likely to have contributed to low prices for high value as well as low value contracts as assessed in 2021. However, access to 5G for MVNOs has been an issue recently in Austria[288] and 5G is not yet available in the service offers of most Austrian MVNOs,[289] which could limit their ability to directly affect prices and offers in the highest level segments. While in interviews an MNO noted that there is a time lag until market developments are reflected at wholesale level and that agreements take time,

282 See for comparison the SIM-only offer of MVNO Happybytes using Telenor's network compared to the offers of incumbent MNO Telenor.. https://mobiltelefoni.no/ (last accessed on 24.03.2023).
283 Based on interview responses.
284 See discussion in WIK (2021) The role of MVNOs in evolving mobile markets https://www.comreg.ie/?dlm_download=the-role-of-mvnos-in-evolving-mobile-markets-report-by-wik-consult-2 (last accessed on 24.03.2023).
285 https://www.rtr.at/TKP/was_wir_tun/telekommunikation/wettbewerbsregulierung/follow-up_merger-H3A_Orange/WholesaleFAQs.de.html (last accessed on 24.03.2023).
286 In addition to directly benefiting MVNOs which made use of the offer, the existence of the Reference Offer is likely to have increased the bargaining power for MVNOs to obtain access lying outside the scope of the merger commitments.
287 See RTR (2015): RTR Telekom Monitor – Jahresbericht 2014, https://www.rtr.at/TKP/aktuelles/publikationen/publikationen/TM_Jahresbericht_2014.pdf (last accessed 19.12.22).
288 In this context it should be noted that while the merger-based commitment ended in 2022, some contracts extend beyond this period, but do not include all technologies. MVNOs claim that competitive wholesale prices for 5G are not commercially available.
289 According to interviews conducted for this study, some smaller MVNOs, e.g. specialised in student tariffs, succeeded in making 5G niche offers, but these are closely coordinated with the MNOs.

it is possible that the limitations in competition from MVNOs in 5G-based offers may have contributed to higher rates for 5G data packages compared with countries such as France, Germany, Italy and Spain[290] as shown in Figure 6-12. The price for 5G packages in Austria is driven by MNOs' tariffs with high monthly base fees, as mass-market MVNOs do currently not offer (lower priced) 5G packages for smartphones. It is also understood that there are ongoing discussions about the price adjustment mechanism[291] in the merger commitments[292] in this regard.

Figure 6-12: International price comparison of retail mobile tariffs for 5G data volumes



Source: Tarifica/Bitkom (2022).[293]

Meanwhile research by WIK on the German market from 2017 to 2020[294] suggests that despite the presence of a capacity-based MVNO commitment and obligations to negotiate MVNO access in spectrum licences, the impact of competitive pressure from MVNOs has been limited to low and medium data packages, where they competed with MNO sub-brands and resellers. MNOs were able to maintain significantly higher prices for their main brands.. More recently, high and unlimited data volume offers including offers from MVNOs,[295] have become more common in the German market but remain

290 Tarifica/Bitkom (2022): Mobilfunkpreise in den Industrienationen – eine Bestandsaufnahme. So schneidet Deutschland im internationalen Vergleich ab, https://www.bitkom.org/sites/main/files/2022-09/220825_Studie_Mobilfunkpreise_Industrienationen.pdf (last accessed on 03.02.2023).

291 See merger commitments - price adustment mechanism that takes in account the retail market situation and the increase of the data consumption.

292 While the merger commitments expired at the end of 2022, some MVNO contracts are longer term

293 Tarifica/Bitkom (2022): Mobilfunkpreise in den Industrienationen – eine Bestandsaufnahme. So schneidet Deutschland im internationalen Vergleich ab, https://www.bitkom.org/sites/main/files/2022-09/220825_Studie_Mobilfunkpreise_Industrienationen.pdf (last accessed on 03.02.2023).

294 See Braun, M.R.; Knips, J.; Wernick, C. (2020): Die Angebotsentwicklung auf dem deutschen Mobilfunkmarkt 2017-2020, WIK discussion paper No. 468 https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_468.pdf (available only in German).

295 MVNO Freenet launched an unlimited offer in 2020 through their brand Freenet Funk https://www.freenet-funk.de/. While Freenet, was using Telefónica's 4G network to offer unlimited data

less prevalent than in other countries.[296] The German Competition Authority has stated in its response to the 2022 consultation on the assignment of 800 MHz, 1,800 MHz and 2,600 MHz spectrum that wholesale access for MVNOs should be implemented to ensure competition in mobile markets. Furthermore, the Competition Authority refers to the communications market report of the Monopolies Commission which also takes the view that the obligation contained in spectrum licences to negotiate MVNO access is insufficient to ensure effective access.[297]

Merger-based commitments to offer capacity-based access to selected players in Ireland have also had limited market impact, with one player (iD mobile) exiting the market, and the other (Virgin mobile) struggling to gain market share, despite benefiting from what appear to have been more attractive wholesale conditions than other MVNOs. The competitive dynamic for low cost unlimited offers in Ireland that has resulted in some of the most attractive prices in Europe for these offers has come not from the remaining MVNO benefiting from the merger commitment or other MVNOs,[298] but from the aggressive pricing strategies of the MNO sub-brands.[299] This may be a feature of the imbalanced market shares amongst the 3 MNOs with the fixed incumbent (owned by French entrant Iliad) acting in some ways as a disruptor.[300] However, it is not clear whether it will persist.

In France, attractive prices in high value offers likely stem primarily from wider competitive dynamics in the 4 player market, which also involves the disrupter Iliad, rather than being driven by competition arising from MVNOs. However, MVNOs have, with support from informal intervention by the NRA, been able to offer 5G-based services due to obligations regarding non-discrimination in MVNO access in spectrum licences. MVNOs have also been considered to play an important role in the provision of business services, in

over 4G, the access agreement was not based on the same terms as the capacity-based wholesale agreement that was reached between MNO Telefónica and MVNO 1&1 in the context of the merger.

296 Offers with unlimited or very high (>50 GB) mobile data volumes are however still far less prevalent in Germany than in many other EU countries (e.g. Ireland, Austria, France, Spain).

297 See Bundeskartellamet (2022): Positionspapier 2022, hier: Stellungnahme des Bundeskartellamtes, B7-401/15, https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Stellungnahmen/Stellungnahme_Frequenzvergabe_BNetzA_2018.pdf?__blob=publicationFile&v=3 (last accessed on 13.02.2023) and Monopolkommission (2021): Telekommunikation 2021: Wettbewerb im Umbruch, 12. Sektorgutachten Gutachten der Monopolkommission, https://www.monopolkommission.de/images/PDF/SG/12sg_telekommunikation_volltext.pdf (last accessed on 13.02.2023).

298 In interviews, MVNOs in the Irish market have noted that the wholesale conditions make it difficult to compete in the provision of unlimited tariffs.

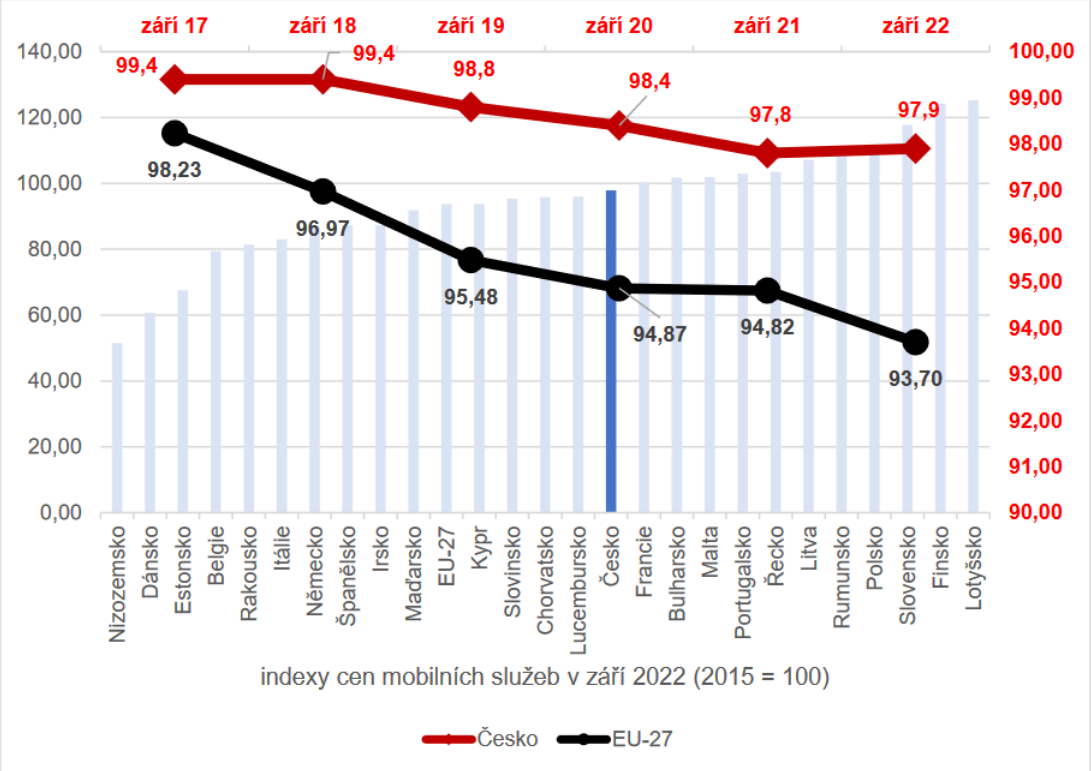
299 As of Feb 2023, the Eir sub brand GoMo charged 14.99€/month for unlimited data, calls and texts while Virgin Media charged 25€/month after an offer phase of 6 months. Tesco Mobile's unlimited offer was priced at 20€/month. See: https://gomo.ie/; https://www.virginmedia.ie/mobile/sim-only/; https://www.tescomobile.ie/sim-only-plans.aspx (last accessed on 03.02.23).

300 Eir has a relatively low market share in mobile subscriptions (15.5% as of end 2021) despite its status as incumbent in the fixed market.

France[301] and an MVNA ecosystem has evolved to support smaller players targeting niche segments.

On the other hand, as shown by data provided by CTU in the context of its draft mobile market analysis, notwithstanding the existence of MVNO obligations in spectrum licences, the Czech Republic clearly stands out as a market characterised by persistently high prices, [302] as well as low data usage and below average download speeds.

Figure 6-13: International comparison of mobile prices in the Czech Republic



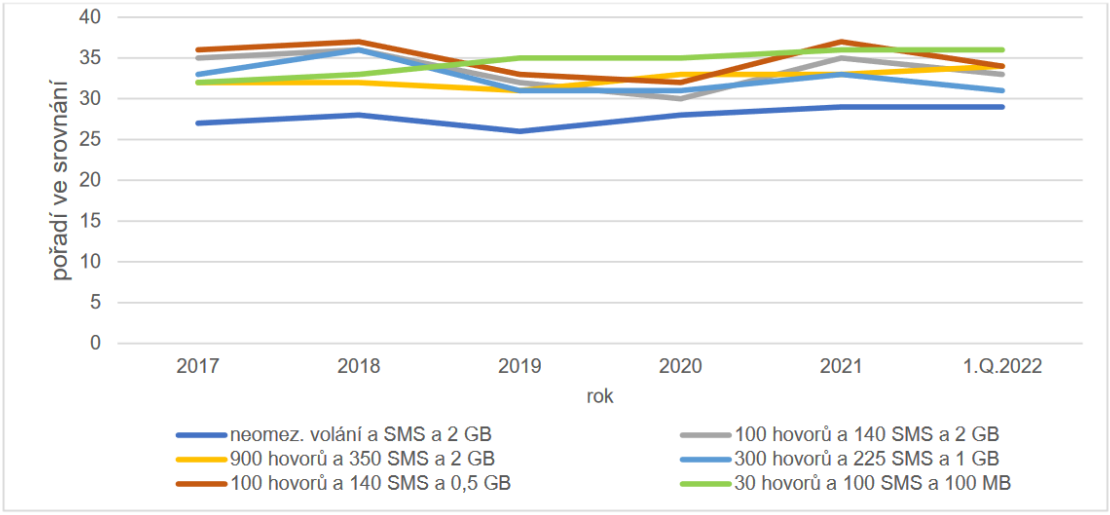
Graf 8: Pozice ČR v mezinárodním srovnání zemí EU v poklesu cen mobilních komunikačních služeb
Zdroj: Eurostat, 2022, dataset HICP - Wireless telephone services , monthly data (index)

Source: CTU (2022): analýzu trhu č. A/3/XX.2022-X,11 trh č. 3 – velkoobchodní trh přístupu k mobilním službám, https://circabc.europa.eu/ui/group/2328c58f-1fed-4402-a6cc-0f0237699dc3/library/465bb79d-3277-4f21-b0af-845ad0898fde/details (last accessed on 24.03.2023).

301 Interviews for this study

302 In the draft market analysis where it proposed a joint SMP finding, CTU noted that an OECD survey in 2022 showed that the Czech Republic is among 32% of countries with the highest prices for mobile voice and SMS services worldwide. In addition, the decline of prices for these services is lower than the average of OECD countries.

Figure 6-14: Level of mobile prices in the Czech republic in relation to OECD countries



Graf 6: Pozice mobilního operátora v mezinárodním srovnání zemí OECD
Zdroj: OECD – TELIGEN, 2022

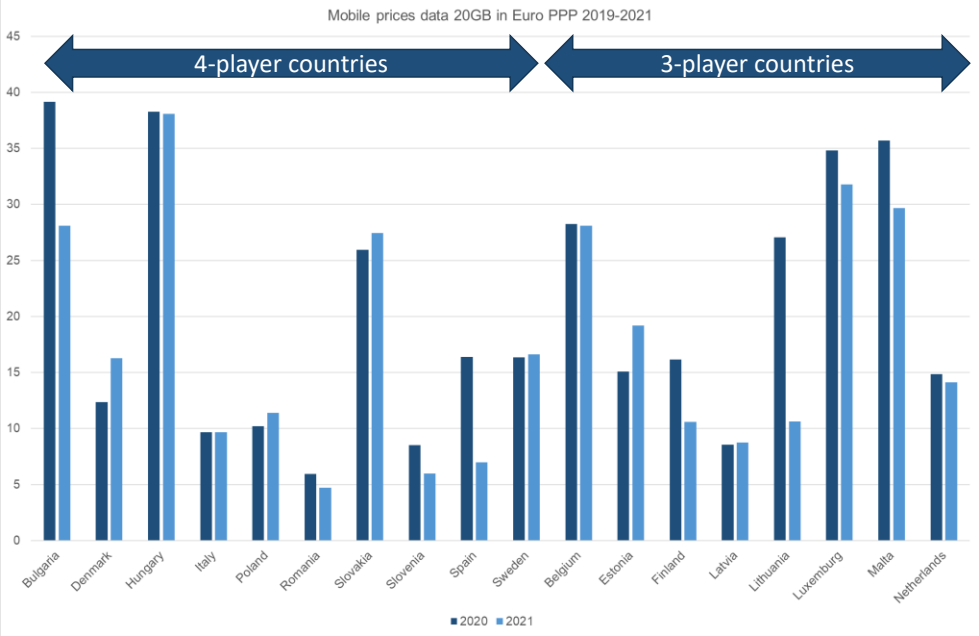
Source: CTU (2022): analýzu trhu č. A/3/XX.2022-X,11 trh č. 3 – velkoobchodní trh přístupu k mobilním službám, https://circabc.europa.eu/ui/group/2328c58f-1fed-4402-a6cc-0f0237699dc3/library/465bb79d-3277-4f21-b0af-845ad0898fde/details (last accessed on 24.03.2023).

In this context, the Czech NRA has highlighted concerns that the structure of prices in both the reference and commercial offers presents an obstacle for MVNOs to provide competitive retail offers, noting that high set-up fees in reference offers and unit-based wholesale pricing in commercial offers for data do not allow MVNOs to compete effectively, in particular in high value offers. The fact that the spectrum licence MVNO obligations require wholesale prices to be set on the basis of an EEO margin-squeeze test in practice limits the potential for MVNOs to engage in price competition.

Outcomes in the markets which do not have MVNO obligations, are also mixed. Positive outcomes can be seen on a number of metrics in Italy, Sweden and Denmark suggesting strong competitive dynamics in these (4 player) markets. However Hungary is characterised by relatively high charges and low download speeds, coupled with limited presence of MVNOs. It may be relevant in this case that the 4th MNO has a very limited market share,[303] and was recently subject to a take-over following the exit of Digi Hungary from the market.[304] Thus, while 4 MNOs are theoretically present, the competitive dynamics may not have been impacted by the smallest player.

303 As of 2022, Digi was reported to have 173,000 mobile customers.
304 4iG acquired acquired Digi Hungary for €625 million in 2022.

Figure 6-15: Mobile prices in selected countries without MVNO obligations 2020-2021 (20GB incl. calls basket in Euro PPP)[305]



Source: European Commission, Mobile and Fixed Broadband Prices in Europe, https://digital-strategy.ec.europa.eu/en/library (last accessed on 10.02.2023).

At least from the snapshot of countries shown in Table 6-5, it is not evident that the presence of MVNO obligations has played a decisive role either way in influencing quality of service for mass-market broadband as indicated by average download speeds. The highest download speeds are reported in Norway, a 3 player country which features strong SMP-based (as well as spectrum-based) regulatory obligations for MVNO access, while the lowest download speeds in this sample of countries can be seen in Ireland, a 3 player country in which merger-based MVNO access exists, but has not played an influential role in the market. Rather as found in an econometric analysis conducted in WIK in a previous study for Ofcom,[306] it seems likely that a wide variety of factors

305 When comparing mobile prices in an international benchmark some methodological issues should be taken into account. The mobile prices shown below cover at least the two largest mobile network operators (based on subscriptions) of the countries in question, but do not include MVNOs. They are calculated based on the least expensive offers per basket and respective operator at a given point in time. Discounts can complicate the analysis and comparability of the data, in particular over time. The same applies for additional features, which are not considered in the benchmark analysis (e.g. zero rating options). Also, in light of deviations in the demand patterns the baskets chosen may be more relevant (in terms of market shares) in some countries and play a less important role in others. in particular, the baskets surveyed tend to be oriented towards the lower end of demand. Accordingly, in advanced countries, products with higher inclusion volumes must sometimes be taken into account for the comparison if the selected baskets are no longer served.

306 WIK-Consult (2015) Competition and investment: an analysis of the drivers of investment and consumer welfare in mobile telecommunications

influences investment and associated quality of service, which may include not only market concentration, but also factors such as coverage and quality of service obligations in licences and associated reporting, timing in relation to the release of new generations of network technology, network sharing, the cost of spectrum, and geographic characteristics affecting roll-out cost.

As applications for quality of service differentiation emerge it will also be important to assess to what extent offers based on 5G network slicing are available in different countries, the types of applications offered, and the degree to which QoS differentiated offers are offered by MVNOs. This capability is likely to be of particular interest to IoT MVNOs, but should also in principle be relevant in the mass-market, where QoS guarantees could be used to support premium packages for gaming or HD video. Although MNOs and (in particular specialist) IoT MVNOs responding to the survey reported that they were planning to offer these services within the next 2 years, as of November 2022 these services were not yet available. The timing and extent of their launch will depend on the pace of deployment of 5G SA, and the involvement of MVNOs in developing these offers will depend on whether they are given access to relevant network slices by their hosts.

Factors which may influence the effectiveness of MVNO obligations

The effectiveness of MVNO obligations in supporting the entry or expansion of MVNOs with the capability to disrupt market outcomes, is likely to depend both on the strength of the obligation itself and the role played by the NRA in enforcement, as well as the details of the pricing and other conditions influencing the ability of an MVNO to differentiate its services from those of its host.

The strongest form of obligation would involve mandating MVNO access ex ante and establishing certain conditions such as pricing principles and an obligation for non-discrimination. This is the approach that has typically been taken in SMP regulation and merger commitments, and should be effective if the terms are appropriately set and effectively enforced. However, previous research by WIK[307] suggests that the impact of merger commitments may be reduced if there are limitations on the beneficiaries of the access obligations because this results in the merging parties alongside the Commission determining which players can enter on attractive terms, rather than leaving the market to determine which player(s) enter and succeed. Thus, it is recommended that any remedies do not unduly restrict the potential beneficiaries of the remedy.

https://www.ofcom.org.uk/__data/assets/pdf_file/0029/78365/competition_and_investment_mobile.pdf (last accessed on 24.03.2023).

307 WIK (2021) The role of MVNOs in evolving mobile markets https://www.comreg.ie/?dlm_download=the-role-of-mvnos-in-evolving-mobile-markets-report-by-wik-consult-2 (last accessed on 24.03.2023).

MVNO obligations linked to spectrum awards are typically lighter than those imposed under SMP regulation (e.g. requiring only negotiation) and less prescriptive regarding the terms of access. This may be sufficient if the market is competitive to a large degree and and the requirement is intended to provide a backstop and the opportunity for (potentially informal) support by the NRA in the event that negotiations break down. However, a generally worded obligation to negotiate is likely to be insufficient if commercial negotiations are not delivering reasonable access conditions and MVNOs are required or expected to play a disruptive role in retail markets (whether for mass-market customers, business or IoT use). In this case more detailed obligations such as those included in the French spectrum licences or indeed in the context of the Austrian merger commitments may be more appropriate. In any event, newly formulated spectrum-based MVNO obligations will need to be justified under the more stringent conditions imposed by Article 52 of the EECC. If such conditions can only be imposed where justified by an analysis of competitive conditions, taking into account the impact on investment, it would be reasonable for spectrum-based MVNO obligations to be more prescriptive and more similar to SMP conditions than may have been the case in the past.

As regards the nature of the obligations, in cases where MVNO obligations are needed to support competitive outcomes in the retail market, experience shows that it is important to establish conditions which would enable the MVNO to act independently of its host to the greatest extent possible. This implies the potential to enter as a “full MVNO” from a technological and operational perspective (within the definition given in Figure 4-6), and conditions which would support VoLTE and give access to new capabilities such as 5G and in future QoS enhanced services at the same or similar timeframe as are available to the host. Moreover, the wholesale pricing regime should enable the MVNO to differentiate its pricing structure from the host including allowing for unlimited data offers. MVNOs interviewed for this study highlight particular challenges with pay per use pricing structures which are not updated to reflect the trend for costs (and prices) of a given amount of data to reduce over time. Capacity-based pricing should offer a solution to this problem in theory, but experience of this measure is limited since it was restricted to specific beneficiaries in the context of merger commitments in Germany and Ireland. The terms and pricing of such arrangements will in any event be important in determining to what extent MVNOs can rely on them to compete effectively in retail markets. As has been the case with wholesale broadband access remedies, if it is considered that MVNO access is essential to support competitive retail dynamics, it may be necessary for the NRA to assess whether capacity-based pricing arrangements would satisfy a margin squeeze test.

Revenue share arrangements have also been highlighted as an approach which provides pricing flexibility, but requires close collaboration between the MNO and MVNO, and is likely to be effective only if there are no conflicts of interest i.e. if the MNO considers that

the MVNO's customer-base is likely to be additive rather than cannibalising its existing customers. Retail minus approaches should also in theory ensure that MVNOs can compete with their host, but limit the degree to which they can differentiate their offers or bundles, or offer competitive prices, in situations where competition at the retail level is insufficient to constrain pricing levels.

It should also be noted that different considerations may apply regarding the wholesale pricing structures that would be suitable for specialist IoT MVNOs, as such providers may not need significant bandwidth but require greater quality assurances. As previously noted, it seems likely that commercial agreement will be reached in most cases, but in situations where intervention is required, a case by case approach may be needed to addressing any detailed issues raised.

In all cases, at the same time as ensuring that access seekers can compete effectively on the retail market, wholesale access obligations relating to mobile connectivity including any rules regarding charges should ensure that the host is able to make a reasonable return on its investments, reflecting the risk taken.

6.1.3 Spectrum for verticals and spectrum leasing

As noted in section 3.1.3, the development of 5G networks can support a variety of use cases including use cases which require communication that is ultra-reliable and offers next to no latency (URLLC), the massive deployment of sensors for dense cities and factories, or automotive connectivity.[308]

Depending on the use case and the business model, the requirements of business use cases for 5G can be delivered via public mobile networks, via local private networks or via quality-assured network slices delivered over public mobile networks. Local private networks can be deployed using direct local licences assigned to non-communication service providers (i.e. industrial firms, public entities, etc.), or via mobile operators.

In this context, to enable and foster the development of industrial use cases, in some countries regulators have reserved spectrum for local use by verticals. Others have attached leasing obligations to the spectrum licenses of the MNOs so that they grant spectrum access to other players as e.g. industrial stakeholders and public institutions in certain circumstances or under given conditions (see the table below).

308 See NGMN Alliance (2018): V2X White Paper, https://5gaa.org/wp-content/uploads/2018/08/V2X_white_paper_v1_0.pdf (last accessed on 19.12.22).

Table 6-6: Spectrum for verticals, spectrum leasing obligations

Country	Spectrum for verticals	Spectrum leasing obligations
Austria	No	No
Belgium	No*	
Bulgaria	No	Yes
Croatia	No	No
Cyprus	No	Yes
Czech Republic	No	Yes
Denmark	No	Yes
Estonia	Yes	No
Finland	Yes	Yes
France	Yes (2.6GHz)	Yes (choice between provision of services and leasing)
Germany	Yes	
Ireland	No	Yes
Greece	No	
Hungary	No	No
Italy	Yes	Yes
Latvia	No	
Lithuania	No	Yes
Luxembourg	No	
Malta	No	Yes
Montenegro	No	
Netherlands	No**	No
Norway	Yes	Yes
Poland	No*	No
Portugal	No	No
Romania	No	
Slovakia	No	
Slovenia	No	Yes
Spain	No	
Sweden	No	No

Notes: * In Belgium and Poland, the regulatory framework is currently being reviewed to enable deployment of local private networks in the 3800-4200 MHz band. ** In the updated NL National Frequency Plan, planning for the 3.5GHz band was changed. 300MHz will now be for mobile use and 100MHz for local use. As of March 2023, a date for auction had not yet been set.
NRAs were asked whether spectrum was set aside (a) for an entrant MNO and / or (b) for verticals / specific use cases

Source: WIK survey Oct-Nov 2022.

Spectrum reserved for verticals

According to responses received from a survey conducted by WIK-Consult in Q4 2022, spectrum has been reserved for local use by verticals in Estonia, France, Finland, Germany and Italy.

Germany amended its regulations in December 2021 to allow campus licence holders to also opt for operator agreements in the 3.7 – 3.8 GHz band.[309] With this regulatory change, MNOs can also use the upper part of the 3.5 GHZ band in Germany but would need to enter into agreements with campus licence holders. The changes aim to make it easier for MNOs and campus licence holders to coexist in the band.[310] In Germany there have been around 226 requests to use spectrum for campus networks. Some deployments have been conducted through co-operations between industrial players and equipment manufacturers (see Annex II (section 8)). However, MNOs have been involved in private network deployment in other cases. One of the first applicants to the local campus licences in Germany was Lufthansa. In February 2020, Vodafone Germany and Lufthansa launched a private 5G network based on standalone technology in an 8 500 m² aircraft hangar in Hamburg, Germany.

In France, spectrum has been available for verticals in the 2.6GHz band since 2020, and 20-30 licences have been issued, although the costs are considered to be high. The Government recently issued a Decree with a view to reducing these costs.[311] Verticals are also experimenting in other bands including 3.8-4.0GHz and 26GHz. ARCEP notes that there are 19 ongoing pilot projects by verticals[312] and the airport operator, ADP Group and its subsidiary Hub One, have been granted a 10-year 4G and 5G licence.[313] Hub One aims to manage and set up the network on behalf of Groupe ADP and Air France. Ericsson has been selected to deploy the private mobile network covering Paris Charles de Gaulle, Paris-Orly and Paris-Le Bourget airports and enable Hub One to

309 See Bundesnetzagentur (2021): Administrative rules for spectrum assignments for local spectrum usages in the 3700-3800 MHz band (Administrative rules for local broadband applications), https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/FrequencyAssignment/LocalBroadband3,7GHz.pdf?__blob=publicationFile&v=2 (last accessed on 16.02.2023).

310 OECD (2022): Develoments in Spectrum Management for Communication Services, OECD Digital Economy Papers, October 2022, No. 332, https://www.oecd-ilibrary.org/docserver/175e7ce5-en.pdf?expires=1676555669&id=id&accname=guest&checksum=D4D2F1295E1F326D9D9776F3833FEBFC (last accessed on 16.02.2023).

311 The Government Decree, published on 03/01/2023 reduces the cost of access to the 2.6 GHz TDD bandwidth. For example, while a company wishing to deploy a private network over an area of 300 m² had until now to pay an annual fee of €70,992 to have access to a 20 MHz band, this will now be reduced to €592.

312 https://www.arcep.fr/cartes-et-donnees/nos-publications-chiffrees/experimentations-5g-en-france/tableau-de-bord-des-experimentations-5g-en-france.html (last accessed on 24.03.2023).

313 European 5G Observatory, 2020.

comply with the new security obligations of France's National Agency for Security of Information Systems.[314]

In Finland 23 licenses have been allocated for local networks in the 2300-2320 MHz and 24.25-25.1 GHz frequency bands (see table in the annex). Local 4G/5G networks are intended for local use, for example, at factories, ports, airports, shopping centres, power plants and mines for their own activities.[315] Furthermore, the City of Tampere is deploying a private network in partnership with EDZCOM (a company of Cellnex) and Signify.[316]

In other countries such as Ireland, spectrum was awarded to a smart grid operator,[317] but a consultation by the NRA on the 26GHz band suggested that there was limited demand for spectrum from other verticals at that time.

Spectrum leasing obligations

An alternative to designating spectrum for verticals is to provide obligations on spectrum leasing. 12 countries have spectrum leasing rules, but in some cases the rules refer to the procedures which apply to spectrum leasing. In Ireland for example, ComReg has established a framework for spectrum leasing, but there is no obligation to lease spectrum. Rather it is a regime to address the process under which transfers are made and ensure there is oversight.[318] However, spectrum leasing for verticals is directly addressed in licence conditions in France and Norway.

During the process of awarding the 3400-3800 MHz band, vertical actors in Norway stressed their need for 5G spectrum in this band for private networks. The government therefore decided that in addition to opening up the 3.8-4.2 GHz-band for verticals, it would introduce an obligation in the 3400-3800 MHz band, that requires license holders to give verticals access to 5G services in the first instance, and secondly spectrum in this band, if they were not able to provide 5G services. The license conditions state that license holders are required to give an applicant access to 5G services or spectrum, if the applicant has needs and requirements that can only be fulfilled by services and spectrum based on this band. If the license holder has offered access to a service in line with the requirements of the applicant and in line with the license obligation terms, then

314 OECD (2022): Develoments in Spectrum Management for Communication Services, OECD Digital Economy Papers, October 2022, No. 332, https://www.oecd-ilibrary.org/docserver/175e7ce5-en.pdf?expires=1676555669&id=id&accname=guest&checksum=D4D2F1295E1F326D9D9776F3833FEBFC (last accessed on 16.02.2023).

315 https://www.traficom.fi/en/communications/communications-networks/existing-radio-licenses-frequency-bands-2300-2320-mhz-and (last access on 04.02.2023).

316 https://www.cellnex.com/trends/tampere-first-finish-city-private-network/ (last accessed on 17.02.2023).

317 https://www.comreg.ie/comreg-completes-the-400-mhz-spectrum-award/

318 ComReg notes in this context that there have been a few spectrum leasing procedures since COVID to address capacity constraints in rural areas (leasing of spectrum from Dense Air and MNOs to Imagine communications, a rural broadband ISP).

the applicant cannot demand access to the spectrum. The applicants' demands must be reasonable and must be compliant with the license terms stated in the original spectrum license. The license holder is required to provide the service or access to spectrum within the geographically limited area of the business location of the applicant. The obligation for spectrum leasing does not apply in geographical areas where the license holder uses the spectrum themselves or plans to do so within one year.[319]

A similar requirement is included in the recently awarded 5G licences in France. In addition to the possibility for verticals to access spectrum directly (discussed above), there is an obligation in the 3.4-3.8Ghz band licences on MNOs to meet reasonable requests from verticals by providing a standard or tailor-made offer, or to lease spectrum.[320] ARCEP notes that this provision will be enforced by the end of 2023, by which time it expects offers for network slicing to emerge.

In the Czech Republic, spectrum leasing obligations are attached to certain 20 MHz frequency blocks auctioned in the 3.4 – 3.6 GHz band which apply for the entire licence's duration. For these blocks license holders must lease the spectrum to interested parties, for a limited geographic area.[321]

Experience with spectrum for verticals and spectrum leasing

Feedback from the interviews conducted for this study indicates that there is a strong interest from verticals in spectrum for local private networks, in particular from large companies.[322] However, most companies have yet to identify concrete use cases and business models for the deployment of 5G campus networks. Standardisation procedures have only been released recently (in 2020 and 2022).[323] This may be one potential reason for the slow development of 5G for verticals, particularly when compared to the

319 Survey answer Nkom.

320 ARCEP (2019): Décision n° 2019-1386 de l'Autorité de régulation des communications électroniques, des postes et de la distribution de la presse en date du 21 novembre 2019 proposant au ministre chargé des communications électroniques les modalités et les conditions d'attribution d'autorisations d'utilisation de fréquences dans la bande 3,4 - 3,8 GHz en France métropolitaine pour établir et exploiter un réseau radioélectrique mobile ouvert au public, https ://www.arcep.fr/uploads/tx_gsavis/19-1386.pdf (last accessed on 16.02.2023).

321 See CTU (2020): Invitation to Tender for Granting of the Rights to Use Radio Frequencies to Provide Electronic Communications Networks in the 700 MHz and 3400–3600 MHz Frequency Bands, Ref. No.: CTU-38 426/2020-613, https://www.ctu.eu/sites/default/files/obsah/ctu/announcement-invitation-tender-granting-rights-use-radio-frequencies-provide-electronic/obrazky/invitationtotenderen.pdf (last accessed on 10.02.2023).

322 Interest was also expressed by one of the Cities interviewed for this study, but on a more speculative basis, while another City noted that 4G and LPWAN solutions were sufficient for most of their applications.

323 3GPP Release 16, which specifically focused on 5G vertical needs was only finalised in early 2020. Work on Release 17, which will also introduce new features for 5G verticals, only recently concluded in March 2022. See VVA; Policy Tracker and LStelcom (2022): 5G Observatory, Quarterly Report 17, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf (last accessed on 10.02.2023).

rollout of commercial 5G. The costs for 5G connectivity and in particular 5G hardware are seen as another obstacle, when there is uncertainty regarding the potential benefits. Furthermore, the COVID-19 pandemic may have caused delays. Nonetheless, feedback form the survey and from interviews conducted for this study indicate that verticals expect increasing demand for QoS tailored provision and URLLC within 2 years.

A survey conducted by WIK in 2021 showed that the companies applying for spectrum reserved for verticals in Germany are planning to roll-out private networks and 60% of these cases the network will not interface with public mobile networks. The survey was updated in 2022 when around 80% of the respondents indicated that independence from public networks was a very important driver for the implementation of 5G campus networks.[324] In this phase, there is a high share of companies and institutions using spectrum for 5G campus networks in the field of research and development. [325]

According to GSA, the global mobile suppliers association, in Q3 2022 955 customers deployed private mobile networks. 5G was deployed in around 40% of these networks. GSA sees a strong correlation between the number of private network references and countries with dedicated spectrum.[326] Data from the 5G observatory's overview of 5G private networks with major private network projects in the EU[327] seems to confirm this with Germany, France and Finland having the highest number of private networks . Thus, experience with dedicated spectrum for verticals has been broadly positive. However, some NRAs note that they have observed a lack of demand from verticals.

There is limited experience regarding spectrum leasing in a 5G context. This may be because dedicated spectrum has been made available in countries where there was significant demand, while in two of the three countries in which there are clear spectrum leasing obligations (France and Norway), leasing obligations apply only if MNOs do not meet reasonable requests for quality-assured services.

Relevance of dedicated spectrum for verticals and spectrum leasing

The OECD notes that addressing the needs of key vertical players is of particular importance to enhance the development of 5G and leverage its benefits for the economy. In this context, they note that reserving spectrum for verticals may be an important element in spectrum management to ensure that key vertical sectors' requirements are

324 https://www.wik.org/uploads/media/Abschlusspraesentation_Entwicklung_von_5G-Campusnetzen_in_Deutschland_und_Europa.pdf.

325 Information from interviews and Franken, M.; Sörries, B. and Stronzik, M. (2021): Entwicklung von 5G Campus-Netzen in Deutschland, in: Netzwirtschaften & Recht, 6/202, pp. 257-320, 18. Jahrgang, https://www.wik.org/fileadmin/Aufsaetze/Entwicklung_von_5G-Campusnetzen_in_Deutschland_NuR_6_2021_275-281.pdf (last accessed on 10.02.20239.

326 GSA (2022): Private Mobile Networks, https://gsacom.com/paper/private-mobile-networks-december-2022-summary-report/ (last accessed on 04.02.2023).

327 See https://5gobservatory.eu/5g-private-networks/#.

identified and to foster close collaboration between vertical industries and 5G civil-infrastructure.[328]

More specifically, as MNOs interviewed for the study mostly indicate that deployment of full 5G capabilities (including 5G network slicing) will take several years, providing dedicated spectrum for verticals could offer an opportunity for businesses that wish to do so, to accelerate the process and experiment with 5G deployments which are tailored to their specific use case and business needs.

In addition, reserving spectrum for verticals has the advantage of enabling a broader approach to the development of solutions for business use cases. There are some industrial players whose needs may not be adequately addressed by mobile operators, e.g. due to overly specific service requirements (that may not be economically feasible to meet via network slicing), a lack of business interest in 5G coverage in the local area of the industrial player, and due to the fact that some industrial players may want to retain full control of their network for data security or cost reasons.[329]

Another advantage of reserving spectrum for verticals, is that even if 5G local networks are deployed by MNOs or in cooperation between companies and MNOs, the potential to rely on their own spectrum increases the countervailing bargaining power of verticals as they either can chose to operate the 5G campus network themselves or ask an MNO, specialised MVNO or other players such as equipment manufacturers to deploy the network. This should increase the competitive constraints on MNOs and encourage them to propose attractive offers.

On the other hand, it is clear from interviews that dedicated spectrum is not an ideal solution in all cases. MNOs and NRAs note that it is likely to be exploited mainly by larger organisations, and that SMEs may be better served via solutions based on network slicing.[330] In addition, use cases that require widespread (even global) connectivity cannot be met through localised private networks alone, and require interaction with the public network, which is currently possible only when engaging with MNOs or MVNOs with the relevant capabilities. MNOs also cite potential disadvantages in reserving

328 OECD (2022): Developments in spectrum management for communication services, OECD Digital Economy Papers, No. 332, OECD Publishing, Paris, https://doi.org/10.1787/175e7ce5-en (last accessed on 10.02.2023).

329 RSPG (2019): RADIO SPECTRUM POLICY GROUP STRATEGIC SPECTRUM ROADMAP TOWARDS 5G FOR EUROPE RSPG Opinion on 5G implementation challenges (RSPG 3rd opinion on 5G), RSPG 19-007 Final, https://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG19-007final-3rd_opinion_on_5G.pdf (last accessed on 10.02.2023).

330 For small and medium-sized enterprises, the problems and uncertainties tend to outweigh the benefits, as they do not have the financial and human resources to carry out pilot projects Franken, M.; Sörries, B. and Stronzik, M. (2021): Entwicklung von 5G Campus-Netzen in Deutschland, in: Netzwirtschaften & Recht, 6/202, pp. 257-320, 18. Jahrgang, https://www.wik.org/fileadmin/Aufsaetze/Entwicklung_von_5G-Campusnetzen_in_Deutschland_NuR_6_2021_275-281.pdf (last accessed on 10.02.2023).

spectrum for private networks. For example, they point out the risk of underused spectrum, as private networks fulfil niche needs while public networks can offer services to a broad range of users on the same spectrum band. Furthermore, mobile operators note private networks can be deployed accessing spectrum resources through mobile operators with sharing and leasing agreements, in addition to commercial provisioning agreements.[331]

It is therefore prudent to take a case by case approach, taking into account supply and demand conditions in the market. Where there is clear demand for dedicated spectrum from verticals and/or a material risk that verticals' needs may not be met by MNOs, spectrum could be dedicated for campus networks. Where the degree of demand is less clear, obligations such as those in France and Norway could be considered, under which MNOs are obliged to lease spectrum if they are unable to meet reasonable demands for quality-assured services from verticals.

6.2 Possible solutions to facilitate competition and switching in cross-border IoT

eSIM has the potential to be deployed in a variety of IoT use cases with a focus on "moving objects" (e.g. cars, drones, smart glasses, VR headsets, containers). It can also be installed in fixed objects at a factory in one location and shipped to multiple locations cross-border (e.g. smart meters).[332] In this context, problems can arise both in the provision of cross-border connectivity for such services, and in the potential for end-users (including verticals) to switch connectivity provider at a later stage.

Fostering competition in the supply of cross-border IoT

Global connectivity solutions are needed for objects which are by their nature mobile, and consistent with the principle of free movement of goods, services and people within the EU, it is possible that a connected object such as a car purchased in one EU Member State could be used primarily or even permanently in another. This can create tensions between the interests of MNOs which operate as national carriers offering service contracts for use in specific countries (even if they operate in a number of countries) and OEMs and associated verticals and specialist MVNOs providing global IoT connectivity and applications, which typically take a more pan-European or global perspective, and seek to ship connected (or connectable) goods and supply services cross-border.

331 GSMA (2021b): Mobile Networks for Industry Verticals: Spectrum Best Practice, GSMA Public Policy Position, https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Mobile-Networks-Industry-Verticals.pdf (last accessed on 10.02.2023).

332 WIK (2021) Strategies to promote over-the-air provisioning https://www.comreg.ie/publication/annex-wik-report-on-strategies-to-promote-over-the-air-provisioning (last accessed on 24.03.2023).

While large MNO groups make use of their own networks alongside roaming agreements that they can secure with the aid of countervailing buyer power resulting from the high volumes of traffic that they manage and the potential to provide wholesale roaming in their home markets, specialist IoT MVNOs are typically reliant on a combination of commercially negotiated MVNO access and roaming, and may in practice rely on permanent roaming to support mobile devices in some situations.

While primarily designed to address roaming for personal communications in the context of travel, the Roaming Regulation[333] recognises the relevance of roaming (including permanent roaming) for M2M communications. For example, the regulation notes that "Subject to the limitations on permanent roaming included in this Regulation, machine-to-machine communications, namely services involving an automated transfer of data and information between devices or software-based applications with limited or no human interaction, are not excluded from the scope of this Regulation or the relevant wholesale roaming access obligations laid down in this Regulation".[334]

Although permanent roaming is subject to commercial negotiation, it further notes that "in order to allow the development of more efficient and competitive markets for machine-to-machine communications, it is expected that mobile network operators will increasingly respond to and accept all reasonable requests for wholesale roaming agreements on reasonable terms and explicitly allow permanent roaming for machine-to-machine communications."

In practice, however, it can be a challenge to clearly distinguish between M2M and person-to-person communication, and this can be subject to interpretation on a case-by-case basis. The uncertainties regarding the identification of use cases as involving IoT are greatest for those use cases that involve some degree of human interaction. In turn, this interpretation has implications for the permanent roaming allowances.

The Roaming Regulation requires[335] BEREC to collect data regularly from national regulatory authorities inter alia on "the development of machine-to-machine roaming and IoT devices, and on the extent to which wholesale roaming agreements cover quality of service and give access to different network technologies and generations." Under Recital 68 "BEREC should also collect the necessary data to allow the monitoring of the elements to be assessed in the Commission's reports on the development of machine-to-machine roaming and IoT devices provided for in this Regulation, taking into account cellular connectivity solutions based on unlicensed spectrum."

333 https://eur-lex.europa.eu/eli/reg/2022/612 (last accessed on 24.03.2023).
334 Recital 21
335 Article 21(2)

MVNOs engaged in cross-border IoT have cited challenges in obtaining commercial roaming solutions in countries where the MNOs are vertically integrated, and thus compete with specialist MVNOs. They also note that it is important to be able to provide access in all countries to compete on contracts for global IoT connectivity.[336]

In this context, there may be a case for NRAs to investigate and if necessary take action on MVNO and/or roaming conditions for IoT in cases where negotiations are reported to have failed.

In addition, when the time comes to review the Roaming Regulation, it may also be worth considering whether amendments are needed to reflect cases where permanent roaming may be needed for cross-border M2M, whether the current definition of M2M[337] may unduly restrict the provision of roaming in cases where connectivity is provided to moving objects for both M2M and personal communications, and whether more explicit provision is needed to support the standardisation of and enable access to quality-assured roaming services that are needed to support well-defined cross-border use cases, such as connected cars.

Facilitating switching in cross-border IoT

eSIM should in theory enable end-users to switch their connectivity provider remotely, and this is particularly important to ensure that end-users can exercise choice when they operate multiple connected devices in the field. However, due to the way in which the M2M eSIM standard is designed, end-users may encounter difficulties in switching if they opt for a third party to control the Subscription Manager Secure Routing (SM-SR), as in this case switching will only be possible if the original connectivity provider maintains control over the SM-SR following the switch or engages in a data swap. The best solution would be an adaptation of the standards to give the end-user more control over the switching process, as is already the case in the consumer eSIM specification. BEREC could thus engage with relevant standards bodies to assess progress in amending the M2M eSIM specification. In the meantime, support could be provided to enterprise customers through the preparation of model contract terms which could be used to ensure that the donor operator collaborates in the switching process and does not exploit its control for example by setting unreasonable exit charges.[338]

336 Feedback from interviews conducted for this study.

337 Recital 21 M2M is described as services involving an automated transfer of data and information between devices or software-based applications with limited or no human interaction.

338 Further discussion of this topic is provided in WIK-Consult (2021) Strategies to promote over-the-air provisioning https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 24.03.2023).

6.3 Possible solutions regarding bottlenecks and switching barriers at the equipment / OS layer

As noted in section 4.2.5, as the eSIM is installed during the manufacture of equipment and the interface is controlled through software, there is the potential for OEMs / OS providers to supply devices with connectivity pre-installed (more likely with IoT and secondary devices) or to steer users to specific connectivity providers.

Technical standardisation plays a central role in the interaction between the hardware, the functions in the mobile network and subscriber management, as well as the services offered to end customers. In this context, encouraging the use of standardised solutions for the provisioning and switching of profiles in mobile devices, including secondary devices, would be an important step in increasing competition in connectivity for these devices.

If problems nonetheless remain and if restrictions are applied by a player which has been identified as a "gatekeeper" in relation to a relevant "core platform service" (such as an OS) in the context of the Digital Markets Act[339], these can in principle be addressed under Article 6(6) of the DMA.[340] This provides that: "

> *The gatekeeper shall not restrict technically or otherwise the ability of end users to switch between, and subscribe to, different software applications and services that are accessed using the core platform services of the gatekeeper, including as regards the choice of Internet access services for end users*."

However, the DMA only applies to gatekeepers, and would not cover the case of smaller OS providers that do not fulfil the thresholds of gatekeepers as defined in the DMA. Smaller OEMs/OS providers are unlikely of themselves to have incentives to steer connectivity because they have an interest to reach as many additional end users as possible and thus to be marketed by many mobile service providers.[341] On the other hand, if a major OEM such as car manufacturer is driving the installation of the OS and

339 European Commission (2022b): Regulation (EU) 2022/1925 of the European Parliament and of the Council of 14 September 2022 on contestable and fair markets in the digital sector and amending Directives (EU) 2019/1937 and (EU) 2020/1828 (Digital Markets Act), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R1925 (last accessed on 24.03.2023).

340 Strube Martins, S.; Knips, J, and Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, Diskussionsbeitrag Nr. 490, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf (/last accessed on 22.02.2023).

341 Strube Martins, S.; Knips, J, and Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, Diskussionsbeitrag Nr. 490, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf (/last accessed on 22.02.2023).

mobile connectivity they may have an interest in bundling connectivity in order to benefit from ongoing subscription revenues.

The EECC addresses provider switching, number portability and bundled offers (incl terminal equipment) in the context of consumer protection.[342] Article 106 (1) and (6) EECC provides that:

> *"1. In the case of switching between providers of internet access services, the providers concerned shall provide the enduser with adequate information before and during the switching process and ensure continuity of the internet access service, unless technically not feasible. The receiving provider shall ensure that the activation of the internet access service occurs within the shortest possible time on the date and within the timeframe expressly agreed with the end-user. The transferring provider shall continue to provide its internet access service on the same terms until the receiving provider activates its internet access service. Loss of service during the switching process shall not exceed one working day.*
>
> *National regulatory authorities shall ensure the efficiency and simplicity of the switching process for the end-user.*

…

> *6. …National regulatory authorities may establish the details of the switching and porting processes, taking into account national provisions on contracts, technical feasibility and the need to maintain continuity of service to the end-users. This shall include, where technically feasible, a requirement for the porting to be completed through over-the-air provisioning, unless an end-user requests otherwise. National regulatory authorities shall also take appropriate measures ensuring that end-users are adequately informed and protected throughout the switching and porting processes and are not switched to another provider without their consent."*

With reference to bundled offers Article 107 (1) EECC provides that

> *"1. If a bundle of services or a bundle of services and terminal equipment offered to a consumer comprises at least an internet access service or a publicly available number-based interpersonal communications service, Article 102(3), Article*

342 Ofcom (2020a): Fair treatment and easier switching for broadband and mobile customers Implementation of the new European Electronic Communications Code, https://www.ofcom.org.uk/__data/assets/pdf_file/0023/204980/statement-eecc-revised-proposals.pdf (last accessed on 04.12.2022) and Ofcom (2021): Implementation of the European Electronic Communications Code (EECC), https://www.ofcom.org.uk/__data/assets/pdf_file/0025/226537/eecc-implementation-slides.pdf (last accessed on 04.12.2022).

103(1), Article 105 and Article 106(1) shall apply to all elements of the bundle including, mutatis mutandis, those not otherwise covered by those provisions."

Depending on how articles 106 and 107 of the EECC have been implemented at national level, switching barriers resulting from market behaviour of MNOs/MVNOs probably could be addressed by telecommunications law at national level. This could apply e.g. to smartwatches which are sold on a standalone basis by MNOs or MVNOs together with connectivity services. If terminal devices are sold in a bundle by the MNOs/MVNOs it could be explored whether the rules related to bundled offers apply.

However, as telecommunications law applies to electronic communications providers and not to OEMs, this solution does not solve problems related to the behaviour of OEMs such as cases where a smartwatch maker or car manufacturer bundles connectivity. One possible solution could be to change the telecommunications law so that it also addresses OEMs. This approach has been taken in Denmark, where the definition of terminal equipment has been expanded to include car manufacturers.[343]

Other problems identified by MVNOs in interviews for this study include refusal of major consumer hardware suppliers to supply hardware directly, limitations on access to functionality of certain devices such as the ability to make use of 5G, and a lack of support for essential servers required for secondary devices. Not all these issues are addressed by ex-ante regulation – in particular those relating to refusal to supply.

However, it could be explored whether a refusal to allow mobile connectivity suppliers and thereby consumers to make use of technical functions such as 5G when communication services are supplied by certain providers via the core platform service could constitute a breach of Article 6(6) or other aspects of the DMA. As the download of mobile connectivity profiles and service management could be provided through apps, the terms of the app store and associated charges may also become relevant for providers of connectivity. These issues are also subject to rules established in the DMA.

6.4 Possible solutions to address challenges for vulnerable customers in the switch-off of legacy networks and move to all-digital

As noted in section 0, while effects for most are expected to be positive, the shift to 5G and eSIM, could negatively impact more vulnerable customers as it is likely to be associated with an acceleration in the switch-off of 2G and 3G networks and a shift away from physical stores and in-person support towards app-based provisioning and customer

343 Strube Martins, S.; Knips, J, and Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, Diskussionsbeitrag Nr. 490, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf (/last accessed on 22.02.2023).

support. According to data provided in the survey for this study, consumer MVNOs will be disproportionately affected because a higher proportion of their customers focus on in-store purchase and/or have handsets which do not support 4G or 5G, than is the case for traditional MNOs. MVNOs also report that legacy handsets are more prevalent in certain countries, such as the UK and Ireland, than in others, such as the Czech Republic. IoT MVNOs also report that a non-negligible proportion of their devices are based on older technologies, and eCall is also based on 2G and 3G technology.[344] Switch-off of either 2G or 3G is complete or imminent in many countries, but MNOs have not yet switched off both technologies, and doing so is likely to trigger some disruption.

In this context, Ofcom, the UK telecoms regulatory authorities has set out "expectations"[345] regarding how they want mobile operators to approach the phased switch-off of legacy 2G and 3G mobile services. These include (i) minimising the impact on coverage; (ii) providing information about switch-off in customer contract and the associated summary; (iii) communicating and providing support to customers (providing a minimum of 3-6 months' notice of the steps they need to take, and considering offering discounts on replacement handsets to vulnerable customers); and (iv) identifying other devices such as telecare alarms and payment terminals which rely on 2G or 3G and providing a longer notice period ahead of switch-off in relation to these services.

It is important that in developing such plans MNOs also actively involve MVNOs hosted on their network, and provide sufficient time for MVNOs to adapt their own processes, and communicate with and provide alternative solutions to their customers. An MVNO interviewed for this study suggested in this context that MNOs pursue a co-ordinated plan with MVNOs for the period up to the change of use of spectrum, stop selling handsets which do not support 4G 2 years in advance of spectrum refarming, and carry out a public information campaign.

There could also be a role for public authorities and NGOs to support in this process by providing public information and providing support for vulnerable customers such as the elderly to switch to services such as alarms based on new technologies. Mobile service providers could also consider how to provide alternatives or support customers that may not be familiar with app-based sign-on and service management of connectivity.

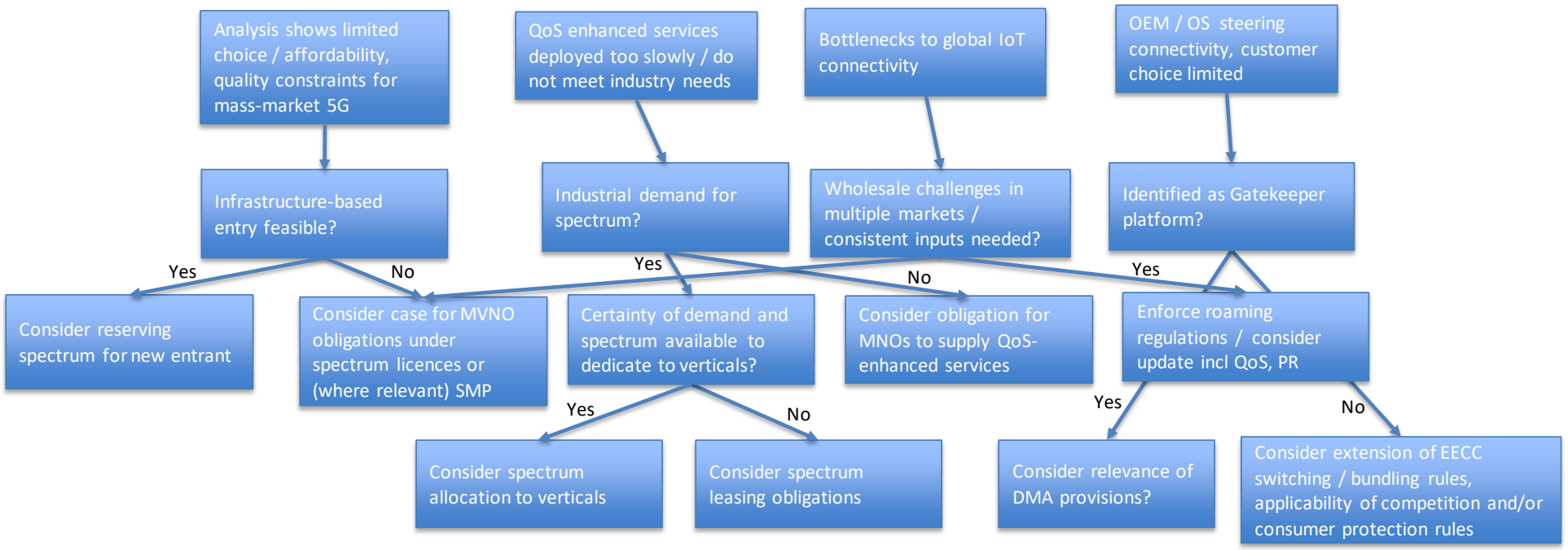
344 See for example https://pfa-auto.fr/wp-content/uploads/2022/03/PTF-ecall-and-2g-3g-network-obsolescence-2022.pdf (last accessed on 24.03.2023).

345 Ofcom (2023): 3G and 2G switch-off – Our expectations of mobile providers, https://www.ofcom.org.uk/__data/assets/pdf_file/0025/252592/3G-and-2G-switch-off.pdf (last accessed on 24.03.2023).

6.5 Overview of challenges and possible solutions

The following figure provides an overview of possible challenges that may arise with the transition to 5G and eSIM along with solutions that may be relevant to consider. The columns map to the themes covered earlier in this chapter, relating to (i) limited choice and concerns around quality and/or price in the mass-market; (ii) industrial needs not being met; (iii) barriers to cross-border IoT connectivity; and (iv) customer choice in connectivity being limited at the OEM/OS level.

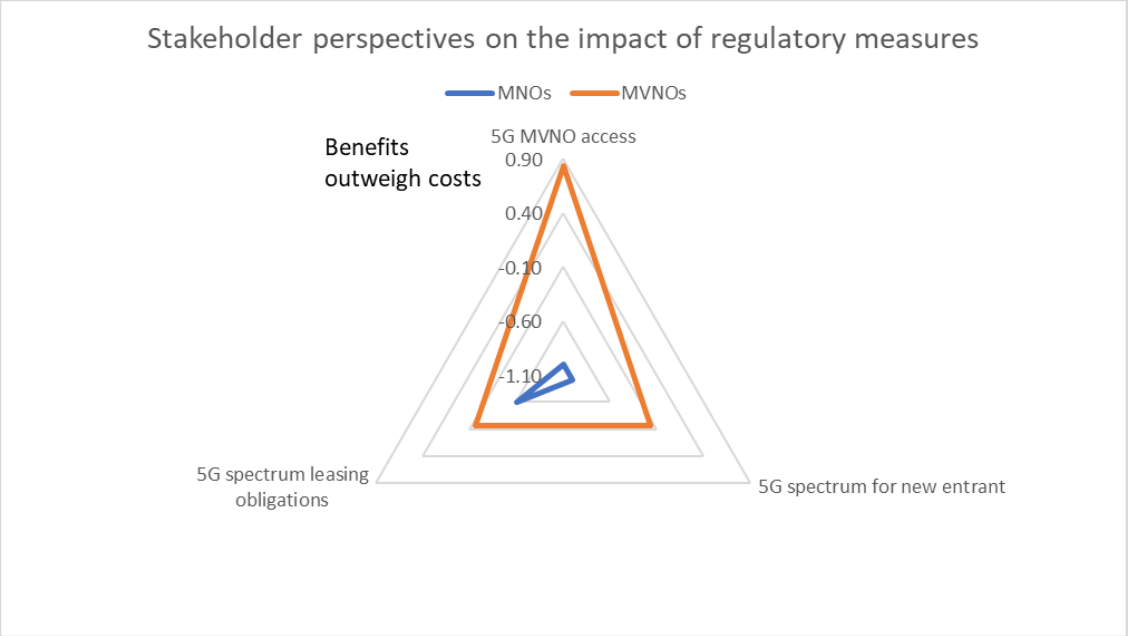
Figure 6-16: Overview of challenges and possible solutions



Source: WIK-Consult

As can be seen in the following figure, different stakeholders have different perspectives on the balance of impacts associated with different approaches. While MNOs take a negative view of all regulatory measures (with a marginally less negative view of spectrum leasing obligations than other approaches), MVNOs responding favoured MVNO access obligations and were somewhat negative about the impacts of other options.

Figure 6-17: Survey results on impact of regulatory measures



Source: WIK survey.

Ultimately, in cases where competition challenges are present, the appropriate solution will depend on the specific case and should follow an analysis of the challenges experienced by end-users, market conditions and the potential effectiveness, costs and benefits of possible solutions in the market or market segments which are affected.

7 Annex I

7.1 Data gathering process

In the data collection phase we conducted interviews and a stakeholder survey with all the relevant stakeholder groups. Further, we analysed evidence based on a documentary and literature review and publicly available datasets. We gathered more extensive information and data on the 6 focus countries Austria, Czech Republic, France, Germany, Ireland and Norway. The countries have been selected because they were of special interest concerning the potential competition challenges associated with 5G, the impact on the value chain, in particular consumers and verticals. Further, the focus countries allow to illustrate the effects of different possible regulatory options for wholesale mobile access.

The focus countries, with the exception of France, currently are characterised by 3 player mobile markets which may have raised attention to possible competition concerns. The 5G coverage lies above the EU average and is expanding in Austria, France, Germany and Ireland. The focus countries provide insight into MVNO obligations implemented in spectrum licenses, SMP based regulation as well as MVNO access imposed in the context of merger obligations.

We conducted interviews with interview partners representing the different levels of the value chain, with a wide geographic reach and with a presence in the focus countries. The table below provides an overview of the number of interviews by stakeholder group and country. Most of the verticals and industrial interview partners address global markets.

Table 7-1: Overview of interviews

Overview of interviews			
Stakeholder group	**Number of interviews**	**Countries**	**Time of the interview**
MNOs	4	All MNOs with international presence, incl. Austria, Ireland, France and Norway of the focus countries	November and December 2022
MVNOs/MVNEs	6	Norway, UK, Austria, Germany, France,	November and December 2022
Verticals and industrial	5	Spain, Sweden, Netherlands, Ireland, Germany	November 2022
Mobile Equipment manufacturers	1	Sweden	November 2022
NRAs	6	Focus countries	October and November 2022

As a complement to the interviews, we collected factual information and qualitative feedback from NRAs, industrial and end-user stakeholders via an online survey. The questions addressed in the survey are included in the annex. The table below provides an overview of the survey answers we received by stakeholder group and country.

Table 7-2: Overview of survey

Overview of survey		
Stakeholder group	**Number of responses**	**Countries**
MNOs	8	Czech Republic, France, Germany, Italy, Spain, Europe (association)
MVNOs/MVNEs	9	Austria, France, Germany, Ireland, Italy,
Verticals and industrial	4	Sweden, Netherlands, Ireland, Germany
NRAs	27	Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Liechtenstein, Lathvia, Lithuaina, Malta, Norway, Montenegro, Netherlands, Poland, Portugal, Serbia, Slovakia, Slovenia, Sweden, Turkey,

7.2 Survey questions

7.2.1 MNO questionnaire

This survey is conducted by WIK-Consult GmbH for a study on behalf of the Body of European Regulators for Electronic Communications (BEREC) about wholesale mobile access connectivity, trends and issues for emerging mobile technologies and deployments.

Our privacy policy can be found here: https://www.wik.org/en/data-protection

If you have any questions regarding this survey, do not hesitate to contact us via mail to Kathrin Grimmer at k.grimmer@wik.org.

7.2.1.1 Background

In which countries do you operate?

Which market segments do you address?

- Mainstream mass-market personal mobile services
- Connectivity for personal secondary devices
- Home IoT
- Budget/low cost segment
- Services targeted at travellers
- Business personal communication services
- B2B IoT/M2M Private (campus) networks
- Specialised services for "verticals" such as automotive, smart city

If you address consumer markets, what is the retail market share for your consumer mobile service (subscribers)? If you are operating in more than one country, please indicate the value for all countries if possible.

7.2.1.2 Technological and service developments

Which of the following capabilities do you support, and which are you planning to offer within the next 2 years?

- Unlimited data
- 5G enhanced mobile broadband
- 5G QoS guaranteed services
- eSIM for primary devices
- eSIM for secondary devices

- eSIM for B2B/IoT/M2M

Please explain challenges in the areas indicated in the previous question

Which spectrum bands are you currently using or planning to use for the provision of 5G services?

- 700 – 800 MHz band
- 3.5 GHz band
- 26 GHz band
- Other

Do you have a 4G/5G private (campus) network offer?

Please elaborate on the nature of your private (campus) network offer

Are you currently offering or planning to offer 5G-based services for the following "vertical" industries?

- Automotive
- Industry/ Production
- Smart Energy
- Agriculture
- Health
- Municipalities/ Government/ Smart City
- Other

Are you involved with or in the near future planning to provide services based on 5G network slicing?

Please specify the services you are providing or planning to provide

If you operate a brand targeting "value"-oriented (low cost) customers: what capabilites are included in this offer?

- No specific "value" offer
- Value offer includes high data volumes or unlimited data
- Value offer includes 5G access
- Value offer includes only basic (4G) services and limited bandwidth

Have you deployed NB-IoT or LTE-M?

7.2.1.3 Demand

Do you foresee increased demand for QoS tailored provision from verticals and business end-users?

When do you foresee increased demand for QoS tailored provision?

Do you foresee demand for ultra-reliable and low latency communications (URLLC)?

When do you foresee demand for ultra-reliable and low latency communications (URLLC)?

Do you foresee demand for Massive Machine Type Communications?

When do you foresee demand for Massive Machine Type Communications?

7.2.1.4 Wholesale connectivity options in practice

How many independent third party MVNOs do you host?

Definitions:

***Full MVNO**s are responsible for the whole infrastructure and value chain with the exception of radio spectrum. They control all the technical and sales operations of the business and have full control over the technical infrastructure. Full MVNOs use their own number ranges and SIM cards.*

***Light MVNO**s do not own any core network infrastructure, but usually operate their own business support services (BSS), including customer care processes, customer relationship management (CRM), customer support, billing processes and billing platform. They can design their own tariff bundles and packages independently from the MNO but may be limited by the wholesale pricing arrangement.*

***Reseller** do not offer their own mobile services, but distribute the services of the host MNO under their own brand or co-branded with the brand of the host MNO. Its responsibility is limited to branding, sales, distribution and marketing.*

***MVNE**s specialize in the B2B sector and act as an intermediary between the MVNOs and the MNOs. MVNEs manage business processes for MVNOs, which MVNOs do not want to or cannot handle themselves. MVNEs can also provide value-added service platforms such as app stores and mobile applications for end-users e.g. related to billing or content.*

Do the conditions of existing MVNO agreements automatically ensure access to the same functionalities available with 5G as are available to the host (e.g. in terms of bandwidth / QoS)?

In which respects can MVNOs differentiate their services in order to compete in the retail market?

- Price
- Customer Service
- Innovative retail services (different services from those of the host)
- Included minutes or bandwidth, incl. the potential to offer unlimited bandwidth
- Other
- None

On what basis are wholesale MVNO access prices set for voice, SMS and data?

Definition:

***Capacity based pricing**: Under the capacity based pricing model, the MVNO buys a certain percentage of the network capacity of the network operator at a fixed price. Payment is however not necessarily all up-front, and there may be a combination of an upfront fee and ongoing charges.*

- Retail minus
- Price per unit (i.e. per minute, SMS or MB)
- Revenue or gross margin sharing
- Capacity based pricing
- Other
- Not applicable

Do the mechanisms used allow MVNO to set retail prices independently from their host?

Is there a mechanism to automatically amend wholesale prices to reflect changes in cost or market dynamics (e.g. the introduction of unlimited data offers) and if so how and how often is this triggered, or are wholesale price changes always subject to negotiation?

Please explain how the mechanism works and whether you consider that the resulting wholesale price enables MVNOs to match or compete on price with their host

Do you offer eSIM support for MVNOs hosted on your network?

Please specificy since when and under which conditions you offer eSIM support for MVNOs?

7.2.1.5 Impacts of technological developments on competition, innovation and consumer welfare

To what extent do you expect that 5G will expand the revenue base (all suppliers) for (a) personal communications; and (b) for IoT?

To what extent do you expect that technological developments such as 5G and eSIM will disrupt the current mobile value chain (a) for personal communications; and (b) for IoT e.g. by bringing in new categories of providers or intermediaries or boosting the role of certain existing players at the expense of others?

Please rank from 1 (lowest / insignificant) to 5 (highest / very significant) the degree to which you consider that technological developments such as 5G and eSIM will lead to the following market changes.

- Increased competition in personal communications services
- Increased competition in IoT
- Reduced operational costs
- Increased investment needs
- New service opportunities
- Greater reliance on online distribution channels
- Trend towards more provision of bundled offers e.g. combining connectivity for primary and secondary devices

Please rank from 1 (lowest) - 5 (highest) the degree to which you consider that 5G and eSIM will contribute to the following trends

- Increased take-up of secondary devices
- Increased take-up of home IoT
- Increase take-up of business IoT
- Increased demand for unlimited data packages

What expectations do you have regarding ARPU for your mobile business following the launch of 5G?

What benefits (if any) have been realised as a result of the presence of MVNOs in your market(s)?

What % of your customers use handsets which are not compatible with 4G or 5G?

What % of your customers use handsets with eSIM capabilities?

What % of your customers purchase mobile services (e.g. top-up cards) in-store?

7.2.1.6 Potential regulatory solution

Please rank the costs and benefits that you consider are associated with the following regulatory obligations

- 5G MVNO access
- Assigning 5G spectrum to a new entrant
- Obligations for lease of 5G spectrum

Please describe the aforementioned costs and benefits

What solutions could be envisaged to mitigate the effects of 2G/3G switch-off on consumers with legacy handsets?

Do you have any other points you want to raise?

7.2.2 MVNO questionnaire

This survey is conducted by WIK-Consult GmbH for a study on behalf of the Body of European Regulators for Electronic Communications (BEREC) about wholesale mobile access connectivity, trends and issues for emerging mobile technologies and deployments.

Our privacy policy can be found here: https://www.wik.org/en/data-protection

If you have any questions regarding this survey, do not hesitate to contact us via mail to Kathrin Grimmer at k.grimmer@wik.org.

7.2.2.1 Background

In which countries do you operate?

What type of MVNO(s) do you operate?

Definitions:

***Full MVNO**s are responsible for the whole infrastructure and value chain with the exception of radio spectrum. They control all the technical and sales operations of the business and have full control over the technical infrastructure. Full MVNOs use their own number ranges and SIM cards.*

***Light MVNO**s do not own any core network infrastructure, but usually operate their own business support services (BSS), including customer care processes, customer relationship management (CRM), customer support, billing processes and billing platform. They can design their own tariff bundles and packages independently from the MNO but may be limited by the wholesale pricing arrangement.*

***Reseller** do not offer their own mobile services, but distribute the services of the host MNO under their own brand or co-branded with the brand of the host MNO. Its responsibility is limited to branding, sales, distribution and marketing.*

***MVNE**s specialize in the B2B sector and act as an intermediary between the MVNOs and the MNOs. MVNEs manage business processes for MVNOs, which MVNOs do not want to or cannot handle themselves. MVNEs can also provide value-added service platforms such as app stores and mobile applications for end-users e.g. related to billing or content.*

Which market segments do you address?

If you address consumer markets, but only provide services for specific market segments (e.g. low cost, travel), what is the reason for not providing mainstream services which compete with MNOs?

If you address consumer markets, what is the retail market share for your consumer mobile service (subscribers)? If you are operating in more than one country, please indicate the value for all countries if possible.

7.2.2.2 Technological and service developments

Which of the following capabilities do you support, and which are you planning to offer within the next 2 years?

- Unlimited data
- 5G enhanced mobile broadband
- 5G QoS guaranteed services
- VoLTE
- eSIM for primary devices
- eSIM for secondary devices
- eSIM for B2B/IoT/M2M

Please explain challenges in the areas indicated in the previous question

Which spectrum bands are you currently using or planning to use for the provision of 5G services?

- 700 – 800 MHz band
- 3.5 GHz band
- 26 GHz band
- Other

Do you have a 4G/5G private (campus) network offer?

Please elaborate on the nature of your private (campus) network offer

Are you currently offering or planning to offer 5G-based services for the following "vertical" industries?

- Automotive
- Industry / Production
- Smart Energy
- Agriculture
- Health
- Municipalities / Government / Smart
- Other

Are you involved with or in the near future planning to provide services based on 5G network slicing?

Please specify the services you are providing or planning to provide

If you operate a brand targeting "value"-oriented (low cost) customers: what capabilites are included in this offer?

- No specific "value" offer
- Value offer includes high data volumes or unlimited data
- Value offer includes 5G access
- Value offer includes only basic (4G) services and limited bandwidth

7.2.2.3 Demand

Do you foresee increased demand for QoS tailored provision from verticals and business end-users?

When do you foresee increased demand for QoS tailored provision**?**

Do you foresee demand for ultra-reliable and low latency communications (URLLC)?

When do you foresee demand for ultra-reliable and low latency communications (URLLC)?

Do you foresee demand for Massive Machine Type Communications?

When do you foresee demand for Massive Machine Type Communications?

7.2.2.4 Wholesale connectivity options in practice

Which MNO(s) host your services?

How many MNOs are there that are willing to agree terms with you for MVNO access in the country/countries in which you operate

Have you benefited from any regulatory intervention supporting your use of MVNO access (or international roaming if you use this as an alternative to MVNO access in some countries)?

In the country or countries in which you operate, in which respects can you differentiate your services in order to compete in the retail market?

- Price
- Customer Service
- Innovative retail services (different services from those of the host)
- Included d minutes or bandwidth incl. the potential to offer unlimited bandwidth
- Other
- None

Do the conditions of existing MVNO agreements automatically ensure access to the same functionalities available with 5G as are available to the host (e.g. in terms of bandwidth / QoS)?

On what basis are wholesale MVNO access prices set for voice, SMS **and data?**

Definition:

Capacity based pricing*: Under the capacity based pricing model, the MVNO buys a certain percentage of the network capacity of the network operator at a fixed price. Payment is however not necessarily all up-front, and there may be a combination of an upfront fee and ongoing charges.*

- Retail minus
- Price per unit (i.e. per minute, SMS or MB)
- Revenue or gross margin sharing
- Capacity based pricing
- Other

Do the mechanisms used allow MVNO to set retail prices independently from their host?

Is there a mechanism to automatically amend wholesale prices to reflect changes in cost or market dynamics (e.g. the introduction of unlimited data offers) and if so how and how often is this triggered, or are wholesale price changes always subject to negotiation?

Please explain how the mechanism works and whether you consider that the resulting wholesale price enables MVNOs to match or compete on price with their host.

Have you experienced challenges related to wholesale access which impede your ability to compete in retail markets or diversify your offer in the way you would wish?

Please specify aforementioned challenges

Are there alternative options realistically available to you, besides MVNO access to provide 5G services such as acquiring spectrum, leasing spectrum, or roaming agreements?

Do you foresee that you may have demand for access to 5G QoS guaranteed network slices from your host?

Do you envisage that you would provide your own eSIM solution, or would you require eSIM support from your host MNO?

Are there / Were there challenges to obtain eSIM support on reasonable terms from your host?

7.2.2.5 Impacts of technological developments on competition, innovation and consumer welfare

To what extent do you expect that 5G will expand the revenue base (all suppliers) for (a) personal communications; and (b) for IoT?

To what extent do you expect that technological developments such as 5G and eSIM will disrupt the current mobile value chain (a) for personal communications; and (b) for IoT e.g. by bringing in new categories of providers or intermediaries or boosting the role of certain existing players at the expense of others?

Please rank from 1 (lowest / insignificant) to 5 (highest / very significant) the degree to which you consider that technological developments such as 5G and eSIM will lead to the following market changes.

- Increased competition in personal communications services
- Increased competition in IoT
- Reduced operational costs
- Increased investment needs
- New service opportunities
- Greater reliance on online distribution channels
- Trend towards more provision of bundled offers e.g. combining connectivity for primary and secondary devices

Please rank from 1 (lowest) - 5 (highest) the degree to which you consider that 5G and eSIM will contribute to the following trends

- Increased take-up of secondary devices
- Increased take-up of home IoT
- Increase take-up of business IoT
- Increased demand for unlimited data packages

With the launch of new technologies such as 5G and eSIM, do you expect that your market share will increase, decrease or stay stable (a) in connectivity for personal devices; (b) IoT?

What expectations do you have regarding ARPU for your mobile business following the launch of 5G?

What benefits (if any) have been realised as a result of the presence of MVNOs in your market(s)?

What % of your customers use handsets which are not compatible with 4G or 5G?

What % of your customers use handsets with eSIM capabilities?

What % of your customers purchase mobile services (e.g. top-up cards) in-store?

7.2.2.6 Potential regulatory solutions

Do you consider that regulatory support may be necessary to sustain your MVNO business?

Please rank and describe the costs and benefits that you consider are associated with the following regulatory obligations

- 5G MVNO access
- Assigning 5G spectrum to a new entrant
- Obligations for lease of 5G spectrum

Please describe the aforementioned costs and benefits:

What solutions could be envisaged to mitigate the effects of 2G/3G switch-off on consumers with legacy handsets?

Can you mention some examples, where NRAs provide informal support for MVNOs? Please name best practices for MVNO supportive measures applied by NRAs (other than regulatory obligations)?

Do you have any other points you want to raise?

7.2.3 NRA questionnaire

This survey is conducted by WIK-Consult GmbH for a study on behalf of the Body of European Regulators for Electronic Communications (BEREC) about wholesale mobile access connectivity, trends and issues for emerging mobile technologies and deployments.

Our privacy policy can be found here: https://www.wik.org/en/data-protection

If you have any questions regarding this survey, do not hesitate to contact us via mail to Kathrin Grimmer at k.grimmer@wik.org.

7.2.3.1 Background

In which country are you present?

Do you have responsibility for spectrum management?

Do you have responsibility for investigations under competition law?

What is the current combined market share of MVNOs in your jurisdiction? What is the market share held by full MVNOs?

MVNOs in this case means independent MVNOs and service providers, i.e. not including secondary brands of MNOs.

***Full MVNOs** are responsible for the whole infrastructure and value chain with the exception of radio spectrum. They control all the technical and sales operations of the business and have full control over the technical infrastructure. Full MVNOs use their own number ranges and SIM cards.*

Please indicate if the market share figure above is confidential

7.2.3.2 Regulatory context

Are there obligations for mobile network operators to offer or negotiate access for MVNOs or other non-MNOs?

Please elaborate the nature of these obligations (incl which technologies / spectrum bands they apply to, what is required in relation e.g. to the provision of access, prices and other conditions of access as well as the parties subject to the obligations and beneficiaries)

What was the legal mechanism through which these obligations were introduced and when (e.g. SMP, merger, spectrum licensing)?

Please describe the mechanism and the relevant obligations in detail. Please also mention if they are linked to specific spectrum bands (if so which).

Which spectrum bands have been assigned for 5G?

- 700-800 MHz band
- 3.5 GHz band
- 26 GHz band
- Other

Was spectrum set aside (a) for an entrant MNO and / or (b) for verticals / specific use cases?

Are there spectrum leasing obligations present in your jurisdiction?

Are there rules in place regarding network sharing in your country?

What kind of network sharing agreements are in place in your country?

7.2.3.3 Technological and service developments

What was the award date / what expectations do you have for the date of award for services based on mid-band and millimetre wave spectrum (if not already in place)?

When do you foresee that 5G population coverage will be substantially complete e.g. based on licence obligations and/or deployment plans?

7.2.3.4 Wholesale connectivity options in practice

As far as you are aware, do the conditions of the MVNO agreements automatically ensure access to the same functionalities that are available to the host (e.g. in terms of bandwidth / QoS)?

In which respects can MVNOs differentiate their services in order to compete in the retail market?

- Price
- Customer service
- Innovative retail services (different services from those of the host)
- Included minutes or bandwidth incl. the potential to offer unlimited bandwidth

- Other
- None
- I do not know

Do the conditions of existing MVNO agreements automatically ensure access to the same functionalities available with 5G as are available to the host (e.g. in terms of bandwidth / QoS)?

On what basis are wholesale MVNO access prices set for voice, SMS and data?

Definition:

Capacity based pricing*: Under the capacity based pricing model, the MVNO buys a certain percentage of the network capacity of the network operator at a fixed price. Payment is however not necessarily all up-front, and there may be a combination of an upfront fee and ongoing charges.*

- Retail minus
- Price per unit (i.e. per minute, SMS or MB)
- Revenue or gross margin sharing
- Capacity based pricing
- Other
- I do not know

Do the mechanisms used allow MVNO to set retail prices independently from their host?

Is there a mechanism to automatically amend wholesale prices to reflect changes in cost or market dynamics (e.g. the introduction of unlimited data offers) and if so how and how often is this triggered, or are wholesale price changes always subject to negotiation?

Please explain how the mechanism works and whether you consider that the resulting wholesale price enables MVNOs to match or compete on price with their host

7.2.3.5 Impacts of technological developments on competition, Impacts of technological developments on competition, innovation and consumer welfare

To what extent do you expect that technological developments such as 5G and eSIM will disrupt the current mobile value chain (a) for personal communications; and (b) for IoT e.g. by bringing in new categories of providers or intermediaries or boosting the role of certain existing players at the expense of others?

What benefits (if any) have been realised as a result of the presence of MVNOs in your market?

- Increased competition for consumers as a whole
- Provision of or greater competition in services for specific consumer groups or consumer applications
- Increased competition for business customers
- Increased competition in IoT connectivity and applications
- Lower prices
- Innovation in customer service
- Innovation in services or bundles
- Technological innovation
- Other
- No benefits

7.2.3.6 Potential regulatory solution

Please rank and describe the costs and benefits that you consider are associated with the following regulatory obligations

- 5G MVNO access
- Assigning 5G spectrum to a new entrant
- Obligations for lease of 5G spectrum

Please describe the aforementioned costs and benefits

Can you mention some examples, where NRAs provide informal support for MVNOs? Please name best practices for MVNO supportive measures applied by NRAs (other than regulatory obligations)?

Do you have any other points you want to raise?

7.2.4 Verticals questionnaire

This survey is conducted by WIK-Consult GmbH for a study on behalf of the Body of European Regulators for Electronic Communications (BEREC) about wholesale mobile access connectivity, trends and issues for emerging mobile technologies and deployments.

Our privacy policy can be found here: https://www.wik.org/en/data-protection

If you have any questions regarding this survey, do not hesitate to contact us via mail to Kathrin Grimmer at k.grimmer@wik.org.

7.2.4.1 Background

In which countries do you operate?

In which business segment(s) do you operate?

- Automotive
- Industry / Production
- Smart Energy
- Agriculture
- Health
- Government / Municipality / Smart City
- Other

7.2.4.2 Technological and service developments

Do your connected devices make use of 5G?

Why are you not making use of 5G?

- 5G is not available in the locations where I need it
- I do not need 5G to meet my requirements
- It would be too costly to make use of this solution
- Unsatisfactory terms and conditions
- Other

Do you make use of (public or private) 5G networks to support connectivity for (a) business locations (e.g. factories); (b) IoT in the field?

Do your connected devices make use of eSIM?

Why are you not making use of eSIM?

- eSIM support is not readily available
- I already have devices which are not eSIM enabled
- I do not need eSIM to meet my requirements
- It would be too costly to make use of this solution
- Unsatisfactory terms and conditions
- No usage of connected devices
- Other

7.2.4.3 Demand

Do you foresee increased demand for QoS tailored provision from verticals and business end-users?

When do you foresee increased demand for QoS tailored provision?

For which applications would QoS tailored provision be used?

Do you foresee demand for ultra-reliable and low latency communications (URLLC)?

When do you foresee demand for ultra-reliable and low latency communications (URLLC)?

For which applications would URLLC be most in demand?

Do you foresee demand for Massive Machine Type Communications?

When do you foresee demand for Massive Machine Type Communications?

For which applications would massive machine type communications be most in demand?

7.2.4.4 Implications of new technologies and services on the value chain

To what extent do you expect that 5G will expand the total revenue base for mobile services (a) for personal communications; and (b) for IoT?

To what extent do you expect that technological developments such as 5G and eSIM will disrupt the current mobile value chain (a) for personal communications; and (b) for IoT e.g. by bringing in new categories of providers or intermediaries or boosting the role of certain existing players at the expense of others?

7.2.4.5 Wholesale connectivity options in practice

Who provides the 5G connectivity for your corporate sites or factories?

- We provide connectivity ourselves using dedicated spectrum
- MNO
- MVNO
- No 5G use
- Other

Who provides the 5G connectivity for your IoT devices?

- We provide connectivity ourselves using dedicated spectrum
- MNO
- MVNO
- We use IoT devices but not 5G
- We do not use IoT devices
- Other

Please explain the reason for your 5G connectivity choice(s)

What options were available to secure connectivity for your sites / devices?

- Dedicated spectrum
- Leased spectrum
- MNO
- MVNO
- Other

What challenges have you had or do you foresee in obtaining mobile access connectivity to serve your business requirements?

7.2.4.6 Impacts of technological developments on competition, innovation and consumer welfare

Has the launch / will the launch of 5G result in more or less options for / competition in the provision of connectivity for your business sites and IoT?

Has the launch / will the launch of 5G result in increased / tailored QoS to support your use cases?

How has / will the availability of eSIM-enabled devices affect the connectivity options available for your business?

How has / will the availability of eSIM-enabled devices affect your ability to switch provider?

What impact do you think that new technologies such as 5G and eSIM will have on competition in consumer and IoT markets?

7.2.4.7 Potential regulatory solutions

Please rank and describe the costs and benefits that you consider are associated with the following regulatory obligations

- 5G MVNO access
- Assigning 5G spectrum to a new entrant
- Obligations for lease of 5G spectrum

Please describe the aforementioned costs and benefits:

Can you provide some examples where NRAs have provided informal support (non-regulatory) which has supported you in obtaining satisfactory mobile connectivity?

Do you have any other points you want to raise?

8 Annex II: Private 5G networks

Table 8-1: Overview of major private 5G networks in the EU (2022)

Date	Country	Company /Entity	Operator	Equipment vendor
2020	Austria	Automotive manufacturer Magna Steyr	A1 Austria	Nokia
2020	Austria	5G playground Carinthia	A1 Austria	Nokia
2020	Austria	Vienna airport	A1 Austria	Nokia
2020	Austria	Siemens renewable energy microgrid	A1 Austria	Nokia
2020	Belgium	Port of Antwerp	Proximus	
2020	Belgium	Port of Zeebrugge	Citymesh	Nokia
2020	Belgium	Brussels Airport	Citymesh	Nokia
2022	Croatia	5G private network solutions	Croatian Telecom	FER
2022	Croatia	AD Plastik		Noia and OIV Digital Signals and Networks
2021	Czech Republic	5G Campus network University of Ostrava Czech Institute of Informatics, Robotics and Cybernetics (CIIRC CVUT)	T-Mobile	Ericsson
2021	Czech Republic	5G Campus network University of Prague (planned)	T-Mobile	Ericsson
2022	Czech Republic	5G StandAlone network at Skoda factory	Vodafone	Nokia
2021	Denmark	Grundfos (pump manufacturer).	TDC NET	Ericsson
2021	Denmark	Maersk Port of Aarhus	Three	

2021	Estonia	Thinnect OÜ		Nokia
2020	Finland	Fortum Power and Heat (State owned energy company)		EDZCOM
2020	Finland	Qualcomm, UROS	Elisa	
2020	Finland	Sandvik mining		Nokia
2021	Finland	KymiRing motor		Nokia, EDZCOM (Cellnex
2021	Finland	Konecranes		Nokia and Edzcom
2021	Finland	Steveco shipping terminals in Kotka		Edzcom and Athonet
2021	Finland	Agnico Eagle Finland Oy Kittilä mine		Nokia, Digita
2022	Finland	City of Tampere (Smart City)		Edzcom and Signify
2019	France	TransDev (mobility)		Ericsson
2020	France	Schnieder Electric	Orange	
2020	France	Lacroix	Orange	Ericsson
2020	France	ADP Group (Hub One) Air France		Ericsson
2020	France	EDF		Thales and Ericsson
2021	France	Private 5G connectivity to enterprise networks in the PB5 La Défense building in Paris		Colt Technology Services, Icade, ADVA, Airspan Networks, Athonet, Accedian and Tibco
2022	France	5G trials at Marseille's Stade Vélodrome	Orange	
2022	France	5G trial at port in France		Blu Wireless
2018	Germany	Port of Hamburg	Deutsche Telekom	Nokia

2019	Germany	German electric microcar company e.GO Mobile AG (Aachen complex)	Vodafone	Ericsson
2019	Germany	Siemens		Qualcomm (5G test network)
2020	Germany	BMW Group Leipzig plant.	T-Mobile	Ericsson
2020	Germany	Bosch		Ericsson
2020	Germany	Centre Connected Industry (CCI)	Deutsche Telekom	Ericsson
2020	Germany	Lufthansa, airline's aircraft hangar in Hamburg airport	Vodafone	Nokia
2020	Germany	Mercedes-Benz, Sindelfingen plant	Telefonica	Ericsson
2020	Germany	Rohde & Schwarz		Nokia
2020	Germany	Volkswagen		
2021	Germany	Deutsche Messe	Deutsche Telekom	Siemens
2021	Germany	Porsche		Ericsson
2022	Germany	Frankfurt Airport (FRAPORT)		NTT
2022	Germany	Umlaut test network		Aispan Network and Druid Software
2022	Germany	Segula Technologies		Cellenex Telecom
2021	Greece	Calpak (solar thermal manufacturer)	COSMOTE	Ericsson
2021	Hungary	Foxconn Komarom factory	Vodafone	Ericsson
2021	Hungary	East-West Gate Intermodal Terminal (EWG)	Vodafone	Huawei
2021	Ireland	Irish Manufacturing Research	Vodafone	Ericsson

2021	Italy	Exor International	TIM	Athonet
2018	Netherlands	Port of Rotterdam - Shell, ABB and ExRobotics	KPN	Huawei
2020	Poland	PGE Systemy		Nokia
2021	Poland	Orange Polska Campus	Orange Polska	Ericsson
2021	Poland	Nokia factory in Bydgoszcz	Orange Polska	Nokia
2022	Poland	Industry 4.0 network in Krakow	Deutsche Telekom	IS-Wireless
2020	Slovakia	CEIT (R&D centre)130	Slovak Telecom	Ericsson
2020	Slovenia	5G connected factory – Iskratel production plant in Kranj	Telekom Slovenia	Iskratel
2019	Spain	FC Barcelona Stadium	Telefonica	Huawei
2020	Spain	BASF	Masmovil	Cellnex, Nokia, Lenovo
2020	Sweden	Atlas Copco	Telenor	Ericsson, Fujitsu
2020	Sweden	Saab		Nokia, Vinnergi
2021	Sweden	Skogforsk	Telia	Ericsson, Volvo, SCA and Biometria
2022	Sweden	X Shore	Tele2	

Note: “The list of private 5G networks in the table below is based on research of publicly available information. It is a non-exhaustive list and the Observatory team endeavour to obtain as much information on published private 5G network deployments as possible.” https ://5gobservatory.eu/5g-private-networks/# (last accessed on 10.02.2023).

Source: https ://5gobservatory.eu/5g-private-networks/# (last accessed on 10.02.2023).

Table 8-2: Local/regional 5G licenses in Finland

License holder	Area of use
Aalto University	Espoo (Otaniemi)
Bayer Ltd.	Turku (indoor use)
Digita Ltd.	Helsinki
Digita Ltd.	Finland
Digita Ltd.	Tampere (indoor use)
Elisa Corporation	Helsinki
Fortum Power and Heat Ltd. Power Station	Loviisa
Jakobstadsnejdens Telefon Ab	Pietarsaari
Nokia Innovations Ltd.	Espoo (indoor use)
Nokia Innovations Ltd.	Oulu (indoor use)
Nokia Innovations Ltd.	Tampere (Teisko)
Nokia Innovations Ltd.	Tampere
Nokia Innovations Ltd.	Helsinki (indoor use)
Nokia Solutions and Networks Ltd.	Espoo (several areas)
Poutanet Ltd.	Nurmijärvi
Savonia University of Applied Sciences	Kuopio (Savilahti)
SSAB Europe Ltd.	Raahe
Turku University of Applied Sciences Ltd.	Turku
Ukkoverkot Ltd.	Iitti
Ukkoverkot Ltd.	Tampere

Ukkoverkot Ltd. (frequency reservation)	Iitti
University of Oulu	Oulu
VTT Technical Research Centre of Finland Ltd.	Oulu
Digita Ltd.	Harjavalta
Centria University of Applied Sciences Ltd	Ylivieska

Source: https://www.traficom.fi/en/communications/communications-networks/existing-radio-licenses-frequency-bands-2300-2320-mhz-and

9 Bibliography

ANACOM (2020): Regulamento n.º 987-A/2020, Regulamento do Leilão para a Atribuição de Direitos de Utilização de Frequências nas faixas dos 700 MHz, 900 MHz, 1800 MHz, 2,1 GHz, 2,6 GHz e 3,6 GHz, https://www.anacom.pt/render.jsp?contentId=1703983 (last accessed on 23.12.2022),

ANACOM (2021a): Regulamento n.º 596-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, https://files.dre.pt/2s/2021/06/125000001/0000200004.pdf (last accessed on 23.12.2022).

ANACOM (2021b): Regulamento n.º 867-A/2021, Regulamento de alteração do Regulamento n.º 987-A/2020, de 5 de novembro, alterado pelo Regulamento n.º 596-A/2021, de 30 de junho, https://files.dre.pt/2s/2021/09/183000001/0000300006.pdf (last accessed on 23.12.2022).

ANACOM (2021c): Operadores Móveis Virtuais em Portugal, Relatório, https://www.anacom.pt/streaming/MVNOemPortugal_maio2021.pdf?contentId=1644333&field=ATTACHED_FILE (last accessed on 16.02.2023).

ARCEP (2019): Décision n° 2019-1386 de l'Autorité de régulation des communications électroniques, des postes et de la distribution de la presse en date du 21 novembre 2019 proposant au ministre chargé des communications électroniques les modalités et les conditions d'attribution d'autorisations d'utilisation de fréquences dans la bande 3,4 - 3,8 GHz en France métropolitaine pour établir et exploiter un réseau radioélectrique mobile ouvert au public, https://www.arcep.fr/uploads/tx_gsavis/19-1386.pdf (last accessed on 16.02.2023).

ARCEP (2022): Observatoire – Les indicateures économiques. Indice des prix des services fixes et mobiles, https://www.arcep.fr/cartes-et-donnees/nos-publications-chiffrees/marches-des-communications-electroniques-en-france-enquetes-trimestrielles-et-annuelles/indice-des-prix-des-services-fixes-et-mobiles.html (last accessed on 24.03.2023).

ARCEP (2023): SERVICES MOBILES 4E TRIMESTRE 2022 OBSERVATOIRE DES MARCHES DES COMMUNICATIONS ELECTRONIQUES, https://www.arcep.fr/fileadmin/cru-1676044269/reprise/observatoire/obs-mobile/2022/t4-2022/obs-mobile-t4-2022_090223.pdf (last accessed on 10.02.2023).

Axon (2021) Impact of 5G and a 4th mobile operator in Belgium https://www.bipt.be/operators/publication/axon-study-of-30-april-2021-on-the-impact-of-5g-and-a-4th-mobile-operator-in-belgium (last accessed 27.03.2023).

Bahia, K. and Castells, P. (2022a): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed in 19.12.2022).

Bahia, K. and Castells, P. (2022b): The dynamic effects of competition on investment: the case of the European mobile communications industry, http://dx.doi.org/10.2139/ssrn.4175243 (last accessed in 07.02.2023).

Baischew, D.; Knips, J.; Godlovitch, I.; Gries, C.; Elbanna, A. and Sörries, B. (2021): Strategies to promote Over-the-air provisioning, study for ComReg, https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 04.12.2022).

BEREC (2018): BEREC Opinion for the evaluation of the application of Regulation (EU) 2015/2120 and the BEREC Net Neturality Guidelines, https://www.berec.europa.eu/sites/default/files/files/document_register_store/2018/12/BoR%20%2818%29%20244_BEREC_Opinion_NN_evaluation_.pdf (last accessed on 19.12.22).

BEREC (2021): International Roaming BEREC Benchmark Data Report October 2020 – March 2021, BoR (21) 115, https://www.berec.europa.eu/sites/default/files/files/document_register_store/2021/10/BoR_%2821%29_115_27th_BEREC_International_Roaming_Benchmark_Data_Report.pdf (last accessed on 07.02.2023).

BEREC (2022a): Guidelines on the Implementation of the Open Internet Regulation https://www.berec.europa.eu/en/document-categories/berec/regulatory-best-practices/guidelines/berec-guidelines-on-the-implementation-of-the-open-internet-regulation-0 (last accessed on 24.03.2023).

BEREC (2022b): BEREC report on the 5G Ecosystem, https://www.berec.europa.eu/system/files/2022-10/BEREC%20BoR%20%2822%29%20144%20Report%20on%20the%205G%20Ecosystem.pdf (last accessed on 19.12.22).

BIPT (2021): Communication du Conseil de l'IBPT du 4 mai 2021 concernant l'impact d'un quatrième opérateur de reseau mobile sur le marché mobile belge, https://www.ibpt.be/file/cc73d96153bbd5448a56f19d925d05b1379c7f21/e6c9b38108e2129e8aeb7361c775d717f66c0ff6/communication_impact_quatrieme_operateur_reseau_mobile_belgique.pdf (last accessed on 03.02.2023).

BNetzA (2019a): Entscheidung der Präsidentenkammer vom 14. Mai 2018 über Anordnung und Wahl des Verfahrens zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz für den drahtlosen Netzzugang – Aktenzeichen: BK1-17/001 – https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/20180514_Auktion2019Entscheidungen_I_II.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=5 (last accessed on 24.03.2023).

BNetzA (2019b): Konsultationsentwurf einer Entscheidung der Präsidentenkammer der Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen über die Festlegungen und Regeln im Einzelnen (Vergaberegeln) und über die Festlegungen und Regelungen für die Durchführung des Verfahrens (Auktionsregeln) zur Vergabe von Frequenzen in den Bereichen 2 GHz und 3,6 GHz. - Aktenzeichen: BK1-17/001 - https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/DrahtloserNetzzugang/Projekt2018/Auktion2019Entscheidungsentwurf_III_IV_pdf.pdf;jsessionid=4B2E60C16A08E47E8318A88660F2A337?__blob=publicationFile&v=2 (last accessed on 24.03.2023).

Bourreau, M.; Yutec, S. and Verboven, F. (2021): Market Entry, Fighting Brands, and Tacit Collusion: Evidence from the French Mobile Telecommunications Market, in : American Economic Review 2021, 111(11), pp. 3459-3499, https://doi.org/10.1257/aer.20190540 (last accessed on 19.01.2023).

Braun, M.R.; Knips, J.; Wernick, C. (2020): Die Angebotsentwicklung auf dem deutschen Mobilfunkmarkt 2017-2020, WIK discussion paper No. 468 https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_468.pdf (available only in German).

Brown, G. (2017): Private LTE Networks – a Heavy Reading white paper produced for Qualcomm Inc., July 2017, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/private-lte-networks.pdf (last accessed on 24.03.2023).

Bundesnetzagentur (2021): Administrative rules for spectrum assignments for local spectrum usages in the 3700-3800 MHz band (Administrative rules for local broadband applications), https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/FrequencyAssignment/LocalBroadband3,7GHz.pdf?__blob=publicationFile&v=2 (last accessed on 16.02.2023).

Bundesnetzagentur (2022): Übersicht der Zuteilungsinhaber für Frequenzzuteilungen für lokale, breitbandige Frequenznutzungen im Frequenzbereich 24.250-27.500 MHz, https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/LokaleNetze/Zuteilungsinhaber26GHz.pdf?__blob=publicationFile&v=19 (available in German only, only organisations listed which agreed to be listed, last accessed on 19.12.22).

Bundeskartellamet (2022): Positionspapier 2022, hier: Stellungnahme des Bundeskartellamtes, B7-401/15, https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Stellungnahmen/Stellungnahme_Frenquenzvergabe_BNetzA_2018.pdf?__blob=publicationFile&v=3 (last accessed on 13.02.2023).

Calzada, J.; Martinez-Santos, F. (2016): Pricing strategies and competition in the mobile broadband market, http://diposit.ub.edu/dspace/bitstream/2445/107806/1/668398.pdf (last accessed 19.12.22).

Canalys (2021): Canalys: Smartphone shipments set to grow 12% in 2021, despite supply pressure, https://canalys-prod-public.s3.eu-west-1.amazonaws.com/static/press_release/2021/82116113Canalys_Smartphone_shipments_set_to_grow_despite_supply_pressure.pdf (last accessed on 19.12.22).

Carrington, Matthew (2023): Mobile IoT: The Impact on the App Development Industry, 20 January 2023, https://www.velvetech.com/blog/iot-mobile-development/ (last accessed on 24.03.2023).

CTU (2020): Invitation to Tender for Granting of the Rights to Use Radio Frequencies to Provide Electronic Communications Networks in the 700 MHz and 3400–3600 MHz Frequency Bands, Ref. No.: CTU-38 426/2020-613, https://www.ctu.eu/sites/default/files/obsah/ctu/announcement-invitation-tender-granting-rights-use-radio-frequencies-provide-electronic/obrazky/invitationtotenderen.pdf (last accessed on 10.02.2023).

CTU (2022): analýzu trhu č. A/3/XX.2022-X,11 trh č. 3 – velkoobchodní trh přístupu k mobilním službám, https://circabc.europa.eu/ui/group/2328c58f-1fed-4402-a6cc-0f0237699dc3/library/465bb79d-3277-4f21-b0af-845ad0898fde/details (last accessed on 24.03.2023).

Curwen and Whalley (2015): The licensing of mobile operators in European markets and the consequences of new entry for competition, Info 17 (3): 16-37, https://www.researchgate.net/publication/276442855_The_licensing_of_mobile_operators_in_European_markets_and_the_consequences_of_new_entry_for_competition (last accessed on 16.02.2023).

Competition and Markets Authority (CMA): Mobile ecosystems -Market study final report, 10 June 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1096277/Mobile_ecosystems_final_report_-_full_draft_-_FINAL__.pdf (last accessed on 24.03.2023).

ComReg (2019): ComReg completes the 400 MHz Spectrum Award, https://www.comreg.ie/comreg-completes-the-400-mhz-spectrum-award/ (last accessed on 24.03.2023).

Coolproducts (2019): Coolproducts don't cost the earth, https://eeb.org/wp-content/uploads/2019/09/Coolproducts-briefing.pdf (last accessed on 19.12.22).

Deloitte (2022): Future of the UK Mobile and Wider Communications Value Chain. Final Report. February 2022, https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/financial-advisory/deloitte-uk-future-of-the-uk-mobile-value-chain-feb-2022.pdf (last accessed on 24.03.2023).

Deutsche Telekom (2021): World first end to end multivendor 5G Voice over NR call, https://www.telekom.com/en/media/media-information/archive/world-first-end-to-end-multivendor-5g-voice-over-nr-call-628746 (last accessed on 19.12.22).

Ericsson (2017): From Healthcare to Homecare – The critical role of 5G in healthcare transformation, June 2017, https://www.ericsson.com/4ac62e/assets/local/reports-papers/consumerlab/reports/2017/healthcare-to-homecare_screen_aw2.pdf (last accessed on 24.03.2023).

Ericsson (2021a): Five ways to a better 5G – Key trends influencing consumer adoption of 5G, https://www.ericsson.com/49944f/assets/local/reports-papers/consumerlab/reports/2021/five-ways-to-a-better-5g-report.pdf (last accessed on 19.12.22).

Ericsson (2021b): Shaping Germany's 5G future – Vodafone's deployment of Europe's first 5G standalone core network, https://www.ericsson.com/en/cases/2021/vodafone-and-ericsson (last accessed on 19.12.22).

Ericsson (2022a): Ericsson Mobility Report, November 2022, https://www.ericsson.com/4ae28d/assets/local/reports-papers/mobility-report/documents/2022/ericsson-mobility-report-november-2022.pdf (last accessed on 19.12.22).

Ericsson (2022b): Percentage of consumers who own a 5G capable smartphone in 2022, In: Statista, https://www.statista.com/statistics/1236180/percentage-5g-subscription-5g-smartphone-by-country/ (last accessed on 19.12.22).

Ericsson (2022c): Voice and communication services in 4G and 5G networks, https://www.ericsson.com/4a19c3/assets/local/reports-papers/white-papers/voice-and-communication-services.pdf (last accessed on 19.12.22).

ETSI (2019): ETSI TR 121 915 V15.0.0, https://www.etsi.org/deliver/etsi_tr/121900_121999/121915/15.00.00_60/tr_121915v150000p.pdf (last accessed on 19.12.22).

ETSI (2021): ETSI TS 122 261 V 16.14.0, https://www.etsi.org/deliver/etsi_ts/122200_122299/122261/16.14.00_60/ts_122261v161400p.pdf (last accessed on 19.12.22).

European Commission (2012): CASE COMP M.6497 Hutchinson 3G / ORANGE COMMITMENTS TO THE EUROPEAN COMMISSION 11 NOVEMBER 2012, https://www.drei.at/media/common/pdf/info/wholesale/2012h3greferenceoffer.pdf (last accessed on 24.03.2023).

European Commission (2013): Final Report of the Hearing Officer (1) Hutchinson 3G Austria/Orange Austria (COMP/M.6497) (2013/C 224/05), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2013:224:FULL&from=EN (last accessed on 24.03.2023).

European Commission (2014a): CASE M.7018 - TELEFÓNICA DEUTSCHLAND/ E-PLUS, MERGER PROCEDURE REGULATION (EC) 139/2004, https://ec.europa.eu/competition/mergers/cases/decisions/m7018_6053_3.pdf (last accessed on 14.02.2023).

European Commission (2014b): Case No COMP/M.6992 HUTCHISON 3G UK / TELEFONICA IRELAND, MERGER PROCEDURE REGULATION (EC) 139/2004, https://ec.europa.eu/competition/mergers/cases/decisions/m6992_20140528_20600_4004267_EN.pdf (last accessed on 14.02.2023).

European Commission (2016): Radio Spectrum Committee – Working Document – Mandate to CEPT to develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union, https://circabc.europa.eu/sd/a/448dc765-51de-4fc8-b6e0-56ed6a1d0bca/RSCOM16-40rev3%205G%20draft_mandate_C (last accessed on 24.03.2023).

European Commission (2022a): COMMISSION DECISION of 17.2.2022 pursuant to Article 32(6) of Directive (EU) 2018/1972 (Withdrawal of notified draft measure), Case CZ/2021/2351: Wholesale market for access to mobile services, C(2022) 888 final, https://circabc.europa.eu/ui/group/2328c58f-1fed-4402-a6cc-0f0237699dc3/library/b9e097fb-de71-437a-9276-74628286567e/details (last accessed on 16.02.2023).

European Commission (2022b): Regulation (EU) 2022/1925 of the European Parliament and of the Council of 14 September 2022 on contestable and fair markets in the digital sector and amending Directives (EU) 2019/1937 and (EU) 2020/1828 (Digital Markets Act),

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R1925 (last accessed on 24.03.2023).

Europawire (2015): Audi Electronics Venture GmbH acquired strategic stake in global forerunner in M2M technology Cubic Telecom, 6 May 2015 https://news.europawire.eu/audi-electronics-venture-gmbh-acquired-strategic-stake-in-global-forerunner-in-m2m-technology-cubic-telecom-765432123456789/eu-press-release/2015/05/06/17/27/39/34210/ (last accessed on 24.03.2023).

Eurostat (2022): Use of Internet of Things in enterprises (2021), May 2022, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Use_of_Internet_of_Things_in_enterprises (last accessed on 24.03.2023).

Federal Ministry for Economic Affairs and Energy (2020): Guidelines for 5G Campus Networks – Orientation for Small and Medium-Sized Businesses, https://www.bmwk.de/Redaktion/EN/Publikationen/Digitale-Welt/guidelines-for-5g-campus-networks-orientation-for-small-and-medium-sized-businesses.pdf?__blob=publicationFile&v=2 (last accessed on 19.12.22).

Franken, M.; Sörries, B. and Stronzik, M. (2021): Entwicklung von 5G Campus-Netzen in Deutschland, in: Netzwirtschaften & Recht, 6/202, pp. 257-320, 18. Jahrgang, https://www.wik.org/fileadmin/Aufsaetze/Entwicklung_von_5G-Campusnetzen_in_Deutschland_NuR_6_2021_275-281.pdf (last accessed on 10.02.20239).

Frid, Albin (2020): eSIM Re-Selling on Mobile App, 29 May 2020, Master'S Thesis at the department of electrical and infomration technology,m, faculty of engineering, Lund University, https://www.eit.lth.se/sprapport.php?uid=1308 (last accessed on 24.03.2023).

Genakos, C.; Valletti, T. and Verboven, F. (2017): Evaluating Market Consolidation in Mobile Communications, cesifo Working Papers 6509 2017, https://www.cesifo.org/en/publications/2017/working-paper/evaluating-market-consolidation-mobile-communications (last accessed on 07.02.2023).

Godlovitch, I.; Stumpf, U.; Sörries, B.; Lucidi, S.; Gantumur T.; Alexiadis P.; Negro, M.; Zaman, R.; de Streel, A. (2018): Review of the Significant Market Power (SMP) Guidelines, report by WIK-Consult for the European Commission, April 2018, https://op.europa.eu/en/publication-detail/-/publication/6eebf7b9-4833-11e8-be1d-01aa75ed71a1/language-en (last accessed on 24.03.2023).

Godlovitch, I.; Wernick, C.; Sörries, B.; Strube Martins, S.; Knips, J.; Wissner, M.; Tenbrock, S.; Franken, M. (2019a): Analysis of the Danish Telecommunication Market in 2030, December 2019, WIK-Consult study for the Danish Energy Agency, https://www.wik.org/fileadmin/Studien/2020/Analysis_of_the_Danish_TK_Market_in_2030.pdf (last accessed on 24.03.2023).

Godlovitch, I.; Lucidi, S. and Sörries, B. (2019b): Competition and investment in the Danish mobile market, https://ens.dk/sites/ens.dk/files/Tele/final_mobile_report_denmark_clean_non-confidential.pdf (last accessed on 10.02.2023).

Godlovitch, I.; Arnold, R.; Gries, C.-I.; Marcus, J.S.; Taş, S. (2019c): Technological developments and roaming, WIK-Consult report for the European Commission,

https://op.europa.eu/en/publication-detail/-/publication/7c74b70b-b4d8-11e9-9d01-01aa75ed71a1 (last accessed 19.12.22).

Godlovitch, I.; Knips, J.; Wernick, C.; Gries, C.; Lucidi, S.; Braun, M.R. (2021): The role of MVNOs in evolving mobile markets, WIK-Consult study for ComReg, https://www.comreg.ie/media/2021/10/ComReg-21101a.pdf (last accessed on 24.03.2023).

Gray, Ross (2022): What is an MVNO (Mobile Virtual Network Operator)? Sierra Wireless IoT Blog, 19 August 2022, https://www.sierrawireless.com/iot-blog/what-is-mvno/#:~:text=Consider%20those%20roaming%20partners%20to%20be%20Mobile%20Virtual,bundle%20that%20it%20then%20sells%20to%20an%20MVNO (last accessed on 24.03.2023).

Gries, C.-I. and Wernick, C. (2017): Bedeutung der embedded SIM (eSIM) für Wettbewerb und Verbraucher im Mobilfunkmarkt, WIK Diskussionsbeitrag Nr. 422, Bad Honnef.

GSA (2022): Private Mobile Networks, https://gsacom.com/paper/private-mobile-networks-december-2022-summary-report/ (last accessed on 04.02.2023).

GSMA (2017): An Introduction to Network Slicing, https://www.gsma.com/futurenetworks/wp-content/uploads/2020/01/1.0_An-Introduction-to-Network-Slicing.pdf (last accessed on 19.12.22).

GSMA (2018): eSIM Whitepaper, The what and how of Remote SIM Provisioning, https://www.gsma.com/esim/wp-content/uploads/2018/12/esim-whitepaper.pdf (last accessed on 04.12.2022).

GSMA (2019): 5G-era Mobile Network Cost Evolution, https://www.gsma.com/futurenetworks/wiki/5g-era-mobile-network-cost-evolution/ or the discussion here: Godlovitch, I.; Knips, J.; Wernick, C. (2020): Benefits of the wholesale only model for fibre deployment in Italy, WIK-Consult report for Open Fiber, https://www.wik.org/fileadmin/Studien/2020/Openfiber_wholesaleonly.pdf (last accessed on 19.12.22).

GSMA (2021a): IMS Data Channel White Paper, https://www.gsma.com/newsroom/wp-content/uploads//NG.129-v1.0-1.pdf (last accessed on 19.12.22).

GSMA (2021b): Mobile Networks for Industry Verticals: Spectrum Best Practice, GSMA Public Policy Position, https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Mobile-Networks-Industry-Verticals.pdf (last accessed on 10.02.2023).

GSMA (2022a): Competition dynamics in mobile markets. An assessment of the effects on network investment and quality in Europe, https://www.gsma.com/publicpolicy/wp-content/uploads/2022/11/Competition-Dynamics-in-Mobile-Markets.pdf (last accessed on 07.02.2023).

GSMA (2022b): 5G mmWave Deployment Best Practices, https://www.gsma.com/futurenetworks/wp-content/uploads/2022/10/GSMA-5G-mmWave-Deployment-Best-Practices-White-Paper-Nov-2022.pdf (last accessed on 19.12.22).

GSMA (2022c): Spectrum leasing in the 5G era, https://www.gsma.com/spectrum/wp-content/uploads/2022/01/Spectrum-Leasing-5G-Era.pdf (last accessed on 19.12.22).

GSMA (2022d): The Mobile Economy 2022, https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/02/280222-The-Mobile-Economy-2022.pdf (last accessed on 24.03.2023).

Hardesty, L. (2021): Google Fi runs TV ads in 6 local markets, 1 June 2021, https://www.fiercewireless.com/operators/google-fi-runs-tv-ads-6-local-markets (last accessed on 24.03.2023).

Hengeler Mueller (2022): Rechtsgutachten Wettbewerbsförderung durch die Diensteanbieterverpflichtung Stellungnahme zum Positionspapier der Bundesnetzagentur erstellt für die freenet AG, https://www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Frequenzen/OeffentlicheNetze/Mobilfunknetze/mobilfunknetze-node.html (last accessed on 17.02.2023).

Iacopino, P. (2022), eSIM in 2022 and beyond: assessing new developments, market trends and consumer behaviour, eSIM Summit at MWC22, https://www.gsma.com/esim/wp-content/uploads/2021/11/MWC22-eSIM-Summit-Main-Presentation-GSMAi.pdf (last accessed on 19.12.2022).

IHS Markit (2019): The 5G Economy – How 5G will contribute to the global economy, November 2019, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/the_ihs_5g_economy_-_2019.pdf (last accessed on 24.03.2023).

IHS Markit, OMDIA, Point Topic (2022), Broadband Coverage in Europe 2021, study for the European Commission, https://digital-strategy.ec.europa.eu/en/library/broadband-coverage-europe-2021 (last accessed on 19.12.22).

ITU-R (2021): ITU towards “IMT for 2020 and beyond”, https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx (last accessed on 19.12.22).

Kalmus, P.; Wiethaus, L. (2010): On the competitive effects of mobile virtual network operators, in: Telecommunications Policy, Volume 34, Issues 5-6, Pages 262-269.

Michel Berne, Pierre Vialle, Jason Whalley, An analysis of the disruptive impact of the entry of Free Mobile into the French mobile telecommunications market, Telecommunications Policy, Volume 43, Issue 3, 2019, Pages 262-277, ISSN 0308-5961, https://doi.org/10.1016/j.telpol.2018.07.007. (last accessed on 24.03.2023).

Monopolkommission (2021): Telekommunikation 2021: Wettbewerb im Umbruch, 12. Sektorgutachten Gutachten der Monopolkommission, https://www.monopolkommission.de/images/PDF/SG/12sg_telekommunikation_volltext.pdf (last accessed on 13.02.2023).

MVNO Europe (2022): Response to BoR (22) 143 Draft BEREC Work Programme 2023, 7 November 2022, https://www.berec.europa.eu/system/files/2022-12/BoR%20PC13%20%2822%29%2011.pdf (last accessed on 24.03.2023).

Neumann, K.H.; Plückebaum, T.; Strube Martins, S. (2016): Network Sharing im Mobilfunk und Festnetz-Mobilfunk-Konvergenz in der Schweiz, WIK-Consult report for BAKOM,

https://www.comcom.admin.ch/comcom/de/home/themen/mobilfunknetz/network-sharing.html (available only in German, last accessed on 24.03.2023).

Neutral Wireless (2022): Standalone 5G Private Network Live in Copenhagen with TV2 for the Danish Elections, https://www.neutralwireless.com/2022/11/danish-election/ (last accessed on 19.12.22).

NGMN Alliance (2018): V2X White Paper, https://5gaa.org/wp-content/uploads/2018/08/V2X_white_paper_v1_0.pdf (last accessed on 19.12.22).

Nokia (n.d.): How 5G will transform live events, https://www.nokia.com/networks/insights/how-5g-will-transform-live-events/ (last accessed on 19.12.22).

Ockenfels, M.; Eltges, F.; Plueckebaum, T.; Godlovitch, I. (2022): Investment and funding needs for the Digital Decade targets, study for the EC, BCO network, to be published.

OECD (2014): Wireless Market Structures and Network Sharing, OECD Digital Economy Papers, No. 243, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxt46dzl9r2-en (last accessed on 24.03.2023).

OECD (2021): Emerging Trends in Communication Market Competition, OECD Digital Economy Papers, September 2021, No. 316, https://doi.org/10.1787/4ad9d924-en (last accessed on 03.02.2023).

OECD (2022): Developments in spectrum management for communication services, OECD Digital Economy Papers, No. 332, OECD Publishing, Paris, https://doi.org/10.1787/175e7ce5-en (last accessed on 10.02.2023).

OFCOM (2016): A cross-country econometric analysis of the effect of disruptive firms on mobile pricing, Research Document, https://www.ofcom.org.uk/__data/assets/pdf_file/0019/74107/research_document.pdf (last accessed on 07.02.2023).

OFCOM (2020a): Fair treatment and easier switching for broadband and mobile customers Implementation of the new European Electronic Communications Code, https://www.ofcom.org.uk/__data/assets/pdf_file/0023/204980/statement-eecc-revised-proposals.pdf (last accessed on 04.12.2022).

OFCOM (2020b): Market Structure, investment and quality in the mobile industry, Economics Discussion Paper Series, Issue Number 1, https://www.ofcom.org.uk/__data/assets/pdf_file/0036/209799/market-structure,-investment-and-quality-in-the-mobile-industry-discussion-paper.pdf (last accessed on 07.02.2023).

OFCOM (2021): Implementation of the European Electronic Communications Code (EECC), https://www.ofcom.org.uk/__data/assets/pdf_file/0025/226537/eecc-implementation-slides.pdf (last accessed on 04.12.2022).

OFCOM (2022): Ofcom's future approach to mobile markets A discussion paper, 9 February 2022, https://www.ofcom.org.uk/__data/assets/pdf_file/0027/231876/mobile-strategy-discussion.pdf (last accessed on 24.03.2023).

OFCOM (2023): 3G and 2G switch-off – Our expectations of mobile providers, https://www.ofcom.org.uk/__data/assets/pdf_file/0025/252592/3G-and-2G-switch-off.pdf (last accessed on 24.03.2023).

Planet Drei (2021): 5G Standalone: Was der neue Mobilfunkstandard alles kann. https://www.drei.at/de/planet-drei/blog/artikel/5g-standalone.html (only available in German, last accessed on 19.12.22).

Qualcomm (2022): Setting off the 5G Advanced evolution, https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/setting-off-the-5g-advanced-evolution-with-3gpp-release-18.pdf (last accessed 20.12.22).

RC Wireless News (2021): Standalone 5G vs. Non-Standalone 5G, https://www.rcrwireless.com/20210907/5g/standalone-5g-vs-non-standalone-5g (last accessed on 19.12.22).

Reinhardt, A. (2022): Pixel 7: Dual eSIM-Support kommt im März 2023, https://www.teltarif.de/dual-esim-pixel-7-pro-maerz-2023-update/news/89630.html (last accessed on 03.11.2022).

RSPG (2019): RADIO SPECTRUM POLICY GROUP STRATEGIC SPECTRUM ROADMAP TOWARDS 5G FOR EUROPE RSPG Opinion on 5G implementation challenges (RSPG 3rd opinion on 5G), RSPG 19-007 Final, https://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG19-007final-3rd_opinion_on_5G.pdf (last accessed on 10.02.2023).

RTR (2015): RTR Telekom Monitor – Jahresbericht 2014, https://www.rtr.at/TKP/aktuelles/publikationen/publikationen/TM_Jahresbericht_2014.pdf (last accessed 19.12.22).

RRT (2020): LITHUANIAN COMMUNICATIONS SECTOR 2019, https://www.rrt.lt/wp-content/uploads/2020/09/Lithuanian-communications-sector-2019.pdf (last accessed on 10.02.2023).

Samsung (2021): Dynamic Spectrum Sharing, technical white paper, https://images.samsung.com/is/content/samsung/assets/global/business/networks/insights/white-papers/0122_dynamic-spectrum-sharing/Dynamic-Spectrum-Sharing-Technical-White-Paper-Public.pdf (last accessed on 19.12.22).

Segan, S. (2022): In These 2 Cities, You Can Finally Make Phone Calls Over 5G, https://uk.pcmag.com/old-wireless-carriers/140720/in-these-2-cities-you-can-finally-make-phone-calls-over-5g (last accessed on 19.12.22).

Sokolov, D. (2022): Garantierte Mobilfunk-Bandbreite erstmals für Privatkunden: Hutchison 3 Austria, https://www.heise.de/news/Garantierte-Mobilfunk-Bandbreite-erstmals-fuer-Privatkunden-Hutchison-3-Austria-7280286.html (last accessed on 19.12.22).

Spark New Zealand (2019): Review of Red Dawn Consulting Report – "MVNO landspace: Global perspectives and New Zealand Applications", https://comcom.govt.nz/__data/assets/pdf_file/0021/158412/NERA-report-for-Spark-Submission-on-mobile-market-study-preliminary-findings-28-June-2019.PDF (last accessed 19.12.22).

Stewart, J.; Nickerson, C. (2021): Costs and benefits of 5G geographical coverage in Europe, Analysys Mason report for Ericsson and Qualcomm, https://www.analysysmason.com/contentassets/81084235a1d9474bb7c0214b68454d58/anaysys-mason-executive-summary-for-5g-geographic-study.pdf (last accessed on 19.12.22).

Streule, I.; Stewart, J.; Bellis, A. (2018): MVNO aspects of the Commission's mobile market review, report for Trustpower, https://comcom.govt.nz/__data/assets/pdf_file/0018/104238/TrustPower-Appendix-2-Analysys-Mason-Submission-on-the-Issues-Paper-26-October-2018.PDF (last accessed 19.12.22).

Strube Martins, S.; Knips, J, and Wernick, C. (2022): eSIM – Potentiale, Anforderungen und Wettbewerbsprobleme, Diskussionsbeitrag Nr. 490, https://www.wik.org/uploads/media/WIK_Diskussionsbeitrag_Nr_490.pdf (/last accessed on 22.02.2023).

Tarifica/Bitkom (2022): Mobilfunkpreise in den Industrienationen – eine Bestandsaufnahme. So schneidet Deutschland im internationalen Vergleich ab, https://www.bitkom.org/sites/main/files/2022-09/220825_Studie_Mobilfunkpreise_Industrienationen.pdf (last accessed on 03.02.2023).

telecoms.com (2018): How 5G will revolutionise the MVNO market, https://telecoms.com/opinion/how-5g-will-revolutionise-the-mvno-market/ (last accessed on 19.12.22).

Telefónica Germany (2021): O_2 succeeds in making Germany's first voice call on the 5G live network, https://www.telefonica.de/news/press-releases-telefonica-germany/2021/09/voice-over-new-radio-vonr-o2-succeeds-in-making-germanys-first-voice-call-on-the-5g-live-network.html (last accessed on 19.12.22).

VVA; Policy Tracker and LStelcom (2022): 5G Observatory, Quarterly Report 17, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf (last accessed on 10.02.2023).

Vodafone (2019): An Industrial 5G Spectrum Policy for Europe, Vodafone Public Policy Paper, https://www.vodafone.com/content/dam/vodcom/files/public-policy/5g-report/an-industrial-5g-spectrum-policy-for-europe.pdf (last accessed on 17.02.2023).

Vodafone (2020): Lufthansa Technik and Vodafone Business have built a standalone private 5G campus network at the 8,500 square meters Lufthansa base at Hamburg Airport Hamburg, 27 February 2020, https://www.vodafone.com/business/news-and-insights/company-news/lufthansa-technik-and-vodafone-business-launch-5g-private-network (last accessed on 24.03.2023).

WIK-Consult (2015) Competition and investment: an analysis of the drivers of investment and consumer welfare in mobile telecommunications https://www.ofcom.org.uk/__data/assets/pdf_file/0029/78365/competition_and_investment_mobile.pdf (last accessed on 24.03.2023).

WIK-Consult (2019) competition and investment in the Danish mobile market https://ens.dk/sites/ens.dk/files/Tele/final_mobile_report_denmark_clean_non-confidential.pdf (last accessed on 24.03.2023).

WIK-Consult (2021) Strategies to promote over-the-air provisioning https://www.comreg.ie/media/2021/11/ComReg-21114a.pdf (last accessed on 24.03.2023).

WIK; Cullen International; ICF (2021) Digital Markets Act Impact Assessment support study https://op.europa.eu/en/publication-detail/-/publication/0a9a636a-3e83-11eb-b27b-01aa75ed71a1/language-en (last accessed on 24.03.2023).

WIK (2021) The role of MVNOs in evolving mobile markets https://www.comreg.ie/?dlm_download=the-role-of-mvnos-in-evolving-mobile-markets-report-by-wik-consult-2 (last accessed on 24.03.2023).

Wood, N. (2022): Voda gives Skoda its very own private 5G SA network, https://telecoms.com/516116/voda-gives-skoda-its-very-own-private-5g-sa-network/ (last accessed on 19.12.22).

Worldbank (2021): Assessment of the Digital Market in Croatia, Final Report, https://openknowledge.worldbank.org/handle/10986/35541 (last accessed on 16.02.2023).

World Economic Forum (2020): The Impact of 5G: Creating New Value across Industries and Society, White Paper in collaboration with PwC, January 2020, https://www.pwc.com/gx/en/about-pwc/contribution-to-debate/wef-the-impact-of-fiveg-report.pdf page 9-10.

Zoz, K.; Plückebaum, T.; Sörries, B.; Elbanna, A. (2022): Abschätzung des Bedarfs an 5G Mobilfunkstandorten für den Frequenzbereich von 3,6 GHz zur Füllung von Lücken zwischen den bestehenden Mobilfunkstandorten, WIK research brief, Bad Honnef (available only in German).

3GPP (n.d.): Releases, https://portal.3gpp.org/#/55934-releases (last accessed on 19.12.22).

3GPP (2020): Release 16, https://www.3gpp.org/specifications-technologies/releases/release-16 (last accessed on 19.12.22).

3GPP (2022a): Release 17, https://www.3gpp.org/specifications-technologies/releases/release-17 (last accessed on 19.12.22).

3GPP (2022b): 5G System Overview, https://www.3gpp.org/technologies/5g-system-overview (last accessed on 19.12.22).

5G ACIA (2019): 5G Non-Public Networks for Industrial Scenarios, White Paper, July 2019 , https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf (last accessed on 24.03.2023).

5G Health (2020): Whitepaper – The need for 5G technologies in the healthcare domain, July 2020, https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf (last accessed on 24.03.2023).

5G Observatory (2018): Quarterly Report 2 – December 2018, http://5gobservatory.eu/wp-content/uploads/2019/01/80082-5G-Observatory-Quarterly-report-2-V2.pdf (last accessed on 19.12.22).

5G Observatory (2020): Quarterly Report 8 – June 2020, http://5gobservatory.eu/wp-content/uploads/2020/07/90013-5G-Observatory-Quarterly-report-8_1507.pdf (last accessed on 19.12.22).

5G Observatory (2021): Telia and Nokia launch standalone 5G in Finland, https://5gobservatory.eu/telia-and-nokia-launch-standalone-5g-in-finland/ (last accessed on 19.12.22).

5G Observatory (2022a): Orange Belgium deploys Standalone 5G, https://5gobservatory.eu/orange-belgium-deploys-standalone-5g/ (last accessed on 19.12.22).

5G Observatory (2022): Quarterly Report 14 – January 2022, https://5gobservatory.eu/wp-content/uploads/2022/02/5G-Obs-PhaseIII_Quarterly-report-14_FINAL-Clean-for-publication_16022022.pdf (last accessed on 19.12.22).

5G Observatory (2022): Quarterly Report 15 – March 2022, https://5gobservatory.eu/wp-content/uploads/2022/05/5G-Observatory-Quarterly-Report-15-May-2022.pdf (last accessed on 19.12.22).

5G Observatory (2022b): Quarterly Report 17 – October 2022, https://5gobservatory.eu/wp-content/uploads/2022/10/QR-17-Final-v3-CLEAN.pdf (last accessed on 19.12.22).

5G Observatory (2022c): Vodafone Germany trials network slicing, https://5gobservatory.eu/vodafone-germany-trials-network-slicing/ (last accessed on 19.12.22).

5G Observatory (n.d.): 5G private networks, https://5gobservatory.eu/5g-private-networks/ (last accessed on 19.12.22).

5G Observatory (n.d.), Overview of commercial 5G launches, https://5gobservatory.eu/overview-5g-commercial-launches/ (last accessed on 19.12.22).