UNOFFICIAL MACHINE TRANSLATION

Financováno Evropskou unií
NextGenerationEU

# 5G mobile network KPIs, 5G indicators and the link to DESI

Prepared for the Ministry of Industry and Trade

[22 September 2024]

Grant Thornton

# Contents

# List of abbreviations and explanations

| | |
|---|---|
| 5G | Fifth-generation networks |
| BNA | Federal Network Agency |
| CRM | Customer Relationship Management |
| CTU | Czech Telecommunications Office |
| DESI | Digital Economy and Society Index |
| DOCSIS | Data Over Cable Service Interface Specification |
| ERP | Enterprise Resource Planning |
| EU | European Union |
| FTTB | Fibre to the Building |
| FTTH | Fibre to the Home |
| FTTP | Fibre to the Premises |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| ISCO | International Standard Classification of Occupations |
| ISP | Internet Service Provider |
| ITU-R | International Telecommunication Union Radiocommunication Sector |
| SME | Small and medium-sized enterprises |
| SA | Stand Alone |
| VHCN | Very High Capacity Network |
| μs | Microsecond |

# Executive summary

This text focuses on key indicators for measuring the performance of 5G mobile networks and their link to the Digital Economy and Society Index (DESI). DESI is a tool used by the European Commission to monitor the digital transformation of EU Member States and is key to supporting policies and investments in this area. Since 2023, the DESI has not been published in a separate report but, in line with the adopted Digital Decade 2030 programme, has been integrated into the annual Digital Decade Progress Reports. As a result, from the 2023 report onwards, the aggregate DESI index is no longer calculated, but its individual indicators continue to be reported in a similar structure within the aforementioned Digital Decade Progress Report. Therefore, where reference is made to the DESI in the following text, we mean the data from the Digital Decade Status Report for 2023 and onwards.

**DESI objectives**

DESI provides an overview of the state of the digital economy and society in EU Member States and collects data across five main dimensions: connectivity, human capital, use of internet services, digital adoption by businesses, and digital public services. This tool identifies areas requiring improvement and highlights differences between Member States, which aids in the development of policies aimed at improving digital infrastructure and skills. DESI also serves as a tool for informed government decision-making and the setting of specific digital transformation targets, and contributes to increasing the competitiveness of Member States whilst supporting the development of digital innovation and capabilities.

**DESI methodology**

DESI is structured into five main dimensions, which include various sub-categories and specific indicators:

1. **Digital Skills**: Assesses the level of digital skills among the population and covers both basic and advanced digital literacy.
2. **Digital infrastructure**: Assesses the availability and quality of broadband connectivity, including mobile broadband and 5G network coverage.
3. **Digital transformation of businesses**: Measures the use of digital technologies in businesses and their integration into business processes.
4. **Digitalisation of public services**: Assesses the level of digitalisation of public services and their accessibility to citizens and businesses.

**The Czech Republic in the context of DESI**

Since 2023, no overall assessment of the DESI index has been produced, and it is therefore not possible to make a comprehensive comparison of the Czech Republic with other EU Member States. In previous reports, when such a comparison was carried out, the Czech Republic achieved rather below-average results in the overall index score. Since 2023, it is therefore more appropriate to evaluate sub-indicators and individual dimensions rather than the DESI as a whole.

In the human capital and digital skills dimension, the Czech Republic achieves an average level. The proportion of the population with at least basic digital skills is 60%, which is above the EU average. However, the proportion of ICT specialists is slightly below average. In the area of public service digitalisation, the Czech Republic is slightly below the EU average, particularly in the field of e-health, where it achieves a significantly lower score than the EU average.

Coverage of households with very high-speed internet (VHCN) in the Czech Republic is significantly below the EU average, mainly due to the low take-up of fibre-optic networks. In 2023, fibre-optic network coverage of households stood at just 36%, the third-worst figure in the EU. This shortfall significantly impacts overall digital connectivity and presents a major challenge for further development.

On the other hand, the availability of 5G networks in the Czech Republic exceeded the EU average for the first time in 2023, which is a positive indicator for further digital development. This progress in the area of 5G networks can serve as a foundation for improving other aspects of digital infrastructure. Strategic focus and investment in the expansion of fibre-optic networks and the improvement of VHCN are key to ensuring better digital connectivity and the Czech Republic's competitiveness in the digital economy.

**Availability of 5G networks in the Czech Republic**

When quantifying the 5G network availability indicator, DESI draws on an external study whose authors obtain data on 5G network availability from national regulators, which in the case of the Czech Republic is the Czech Telecommunications Office. The Office has developed a detailed measurement methodology for calculating 5G network availability, which sets out parameters for drive-by measurements (usable for measuring 5G network availability on corridors and motorways) and stationary measurements. However, as data from stationary measurements in particular is not available, coverage simulations are used to calculate 5G network availability. For this purpose, the CTU uses the ITU-

R P.1812, which simulates signal propagation based on data from base stations. This model includes a detailed analysis of the terrain between the transmitter and receiver and is suitable for calculating cellular network coverage.

The data processed by the aforementioned coverage simulation shows that, according to figures from the Czech Statistical Office, the overall availability of 5G networks in the Czech Republic reaches 96.8% of the population. Among operators, Vodafone has the highest coverage, with 93.2% of the population able to use its 5G network, whilst O2 has the lowest, with its 5G network covering only 84.1% of the population. This data can be disaggregated to the level of basic settlement units (BSUs) to analyse differences in 5G connectivity availability across the Czech Republic. Such an analysis shows that whilst 100% of the population is covered by a 5G signal in two-thirds of ZSJs, connectivity decreases in rural areas with lower population density, particularly in the Czech Republic's border regions. This is also reflected in data on the difference in 5G network availability between urban and rural areas. Rural areas, defined according to the DESI methodology, are home to 22% of the Czech Republic's population (although they account for 73% of the country's area), and 5G network availability in these areas drops to 87.3%. In contrast, in urban areas, more than 99% of the population has access to a 5G network from at least one operator.

In the Czech Republic, with the exception of the operator O2, 5G networks are primarily available in the low-frequency 700 MHz band. Although five operators have obtained licences to operate 5G networks in the mid-band 3.4–3.8 GHz, the availability of 5G connectivity in this band has not yet been sufficiently developed. In total, around a quarter of the population has access to 5G connectivity in the mid-band (data as of June 2024), but there are significant differences between operators. In the case of O2, connectivity in this band is available to more than a fifth of the Czech population, whilst for T-Mobile it is only 15% and for Vodafone 1.3%.

**Comparison of 5G network availability with Germany**

In Germany, 5G technology is available across 92% of the territory, with 5G connectivity available to 99.66% of households. This implies that there are virtually no so-called 'white spots' in Germany, i.e. areas without access to 5G networks. Data from the German regulator even suggests that more than 99% of the population has access to a 5G network from more than one operator. Furthermore, there is a significantly high proportion of standalone (SA) 5G networks in Germany, a technology that operates on its own independent 5G infrastructure. This technology covers 89.9% of Germany's territory, and more than 90% of households have access to SA 5G networks. The use of frequency bands is also an important factor. According to DESI data, the availability of 5G networks in higher frequency bands (3.4–3.8 GHz) will reach 43.8% of households by 2023. Availability in lower frequency bands (700 MHz) therefore continues to predominate, as these are particularly suitable for covering less densely populated areas due to their greater coverage range.

The level of 5G network coverage in the Czech Republic and Germany is therefore roughly comparable, and in both countries the proportion of households with access to 5G networks is above the EU average. On closer inspection, however, it must be noted that the Czech Republic lags behind Germany in terms of 5G network development. Operators in Germany have already made significant investments in building a new, 'proprietary' 5G network core, which is reflected in the widespread availability of SA technology across the country. Operators in the Czech Republic, in the interest of a rapid launch of 5G connectivity, have relied on DSS technology, where the 5G network core is shared with the previous generation. Unlike their German counterparts, all operators in the Czech Republic therefore still have to make significant investments in the transition to SA technology. Operators in Germany are currently focusing primarily on expanding the availability of 5G networks in the mid-frequency bands (3.4–3.8 GHz), particularly in urbanised areas where greater priority must be given to network capacity and other quality parameters. This also entails significant investment in densifying the base station network. Coverage in this band in Germany exceeded two-fifths of the population by the end of 2023 and is expected to continue growing. In this case too, operators in the Czech Republic are lagging behind – although they have held licences to operate 5G networks in the 3.4–3.6 GHz band since the start of 2021, significant investment in the development of connectivity in this band can only be observed in the case of one operator, and the total proportion of the population with access to connectivity in the 3.4–3.6 GHz band thus stands at only around 25%.

**Future development of 5G network availability in the Czech Republic and trends in the context of DESI**

The key barriers and limitations to the development of 5G networks in the Czech Republic stem from the conclusions outlined above. The main constraint on the development of 5G networks in the Czech Republic is linked to the insufficient use of higher frequency bands and the need for investment in SA technology. To improve connection quality and capacity, it will be necessary to increase the proportion of standalone 5G networks and expand the use of the 3.4–3.6 GHz band. In other words, after obtaining licences to operate 5G networks, operators in the Czech Republic have focused on rapidly developing network availability as such. This criterion of population coverage by 5G networks is above average in the Czech Republic within the EU context, and the scope for further growth is already very limited. In the coming period, however, investments in improving the quality of 5G networks are key, and in this area, operators in the Czech Republic are lagging behind other EU countries.

The scope for further increasing 5G network coverage is now rather limited. The 5G signal currently covers 96.8% of the population. This is still a slightly lower proportion than in Germany, for example, but in the EU context it is an above-average figure. However, further expansion of coverage may already face disproportionately high investment costs when calculated per capita of the newly covered population.

In relation to the Czech Republic's ranking in the DESI index, the area of digital infrastructure and connectivity is assessed as below average compared to other EU countries and in relation to the stated goals of the 'Digital Decade'. However, this is not due to 5G network coverage – which is above average compared to other EU countries. The problem for the Czech Republic in the light of the DESI assessment, however, is the trend in gigabit connectivity, caused primarily by the indicator of optical network development. The Czech Republic's relative position in the overall connectivity assessment is therefore likely to deteriorate. It cannot be assumed that, without substantial investment in infrastructure, there will be a significant increase in the proportion of households connected to very high-speed fixed internet in the foreseeable future – the Czech Republic will continue to lag behind in this indicator, whilst the ‘lead’ it currently holds in terms of 5G network coverage will diminish in comparison with other EU Member States. Assuming there is no change to the DESI methodology, i.e. the indicators included in this assessment, it is reasonable to expect a trend of deteriorating ratings for the Czech Republic.

**Qualitative parameters of 5G network availability in the Czech Republic**

There is insufficient robust data on connection quality parameters available for analysis; the assessment must therefore be based on several partial sources. Ad-hoc measurements are taken into account, but their weakness lies in the fact that they are usually commissioned by operators (and published in their media outputs) – and so even if the measurement is carried out using robust technology and by a trustworthy provider, it is necessary to take into account distortions caused, for example, by the commissioning party's selection of suitable locations for measurement. For this reason, other sources were also analysed, such as existing data from measurements on transport corridors and motorways, or independent data produced by users of the NetTest application. This application is developed and operated by the Czech Telecommunications Office (ČTÚ), so the data is considered reliable.

Of the ad-hoc measurements presented by the operators, O2 is the most active, carrying out measurements in collaboration with the Czech Technical University (ČVUT) and claiming that it achieves significantly better results than the other two operators in terms of quality parameters such as download and upload speeds or latency. The average download speed is said to reach almost 300 Mb/s, which is almost double that of the other two operators. The operator attributes this difference primarily to the fact that, although its 5G network has lower population coverage, it is provided significantly more often in the 3.4–3.8 GHz frequency band, where higher speeds and network capacity are achieved. A similar conclusion is suggested by the results of the NetTest app, which also ranks O2 first in terms of both speed and latency, though the gap between it and the other two operators is smaller. However, it is important to bear in mind the limitations of the NetTest app's data analysis, caused by the quality and quantity of the available data. According to NetTest data, the average download speed in the Czech Republic exceeds 200 Mb/s; however, it should be noted that, to eliminate potential distortions, only measurements taken in situations with a very strong signal were taken into account. If measurements taken under poor mobile signal conditions were also included, the result would be significantly worse.

Conversely, data from measurements taken on motorways and major roads by CTU staff place the operator O2 in last place in terms of download speeds. This difference is partly due to poorer 5G network coverage in the case of O2.

Data from the NetTest app can also be used to some extent for an indicative comparison of differences in the quality parameters of 5G network connections in urban and rural areas. The difference is, of course, significant; according to the analysis, connections in cities are up to half as fast again as in rural areas, and lower latency values are also achieved. At the same time, however, there is no direct correlation – connection quality does not decrease in direct proportion to the size of the settlement; other parameters are more decisive (distance from a larger urban area, geomorphological characteristics of the territory, etc.). It should be noted, however, that the use of NetTest data has limited interpretative possibilities due to the number of data inputs that can be included in the analysis, as well as other limitations, primarily related to the fact that the data is generated by the users themselves when performing the connection test. The results of the analysis thus suggest trends rather than providing robust conclusions.

Connections to 5G networks appear to be more stable and of higher quality even in high-load situations (i.e. primarily high concentrations of people) compared to older technologies; however, even with 5G networks, connection quality drops significantly once a certain threshold of connected user density is reached (all the more so when low-frequency bands are used). Operators in the Czech Republic and across Europe are addressing these limitations (whilst simultaneously observing a trend of significantly increased demand for high-quality connectivity compared to the past, or higher data traffic volumes during events with high concentrations of people) by deploying mobile base stations or significantly upgrading infrastructure in stadiums, concert halls and other venues where high concentrations of users can be regularly expected. However, the full potential of 5G networks for managing such situations can only be realised through the application of
"stand-alone" technology.

**Socio-economic benefits and environmental implications of 5G network development.**

The socio-economic benefits of 5G networks are assessed primarily in terms of their impact on gross domestic product (GDP), employment and economic benefits across various sectors.

As early as 2017, the European Commission estimated that in four key strategic sectors (automotive, healthcare, transport and energy), the annual economic benefit could reach up to €113 billion, with the creation of approximately 23 million jobs expected. Other sources also agree on the significant contribution of 5G network development in terms of both GDP and jobs. A 2021 report by the European Court of Auditors, citing estimates from Accenture, for example, states that the roll-out and development of 5G networks could contribute up to €1 trillion to the EU's total GDP between 2021 and 2025 and create or transform up to 20 million jobs. The analyses use various economic models, including input-output modelling, which tracks the flow of goods and services between sectors of the economy, and dynamic panel data.

5G technologies offer specific benefits in particular sectors. In agriculture, they can increase yields by up to 25% and reduce water and energy costs. Benefits in agriculture include the development of precision farming, increased productivity, cost reductions and positive environmental impacts. The development of 5G networks has the potential to deliver significant economic impacts in other sectors as well, to foster innovation and to improve quality of life. These benefits are comprehensive and encompass both direct economic impacts and broader socio-economic effects that contribute to the growth and competitiveness of the European economy.

5G networks offer increased data transmission efficiency, leading to energy savings per unit of transmission. However, overall energy consumption may increase due to the need for a dense network of small base stations. These stations, which are essential for ensuring coverage and capacity, increase the network's overall energy consumption.

In addition to energy-related aspects, environmental costs are also associated with the manufacture and installation of new equipment, which includes the extraction of raw materials, production and logistics. These processes can lead to higher $CO_2$ emissions and the generation of electronic waste. There are also concerns about increased electromagnetic radiation caused by a dense network of small cells, which may lead to restrictions on infrastructure development.

# Management summary

This text focuses on key indicators for measuring the performance of mobile 5G networks and their connection to the Digital Economy and Society Index (DESI). DESI is the European Commission's tool for monitoring the digital transformation of EU Member States and is key to supporting policies and investments in this area. Since 2023, DESI has not been published in a separate report but, in accordance with the adopted Digital Decade 2030 programme, has been integrated into the annual Reports on the State of the Digital Decade. Consequently, the summary DESI index is no longer calculated from the 2023 report onwards, but its individual indicators continue to be reported in a similar structure within the aforementioned Report on the State of the Digital Decade. Thus, where DESI is referred to in the following text, we refer to the data from the Report on the State of the Digital Decade for 2023 and beyond.

**Objectives of DESI**

DESI provides an overview of the state of the digital economy and society in EU Member States and collects data across five main dimensions: connectivity, human capital, use of internet services, integration of digital technologies by businesses, and digital public services. The tool identifies areas for improvement and highlights differences between Member States, helping to shape policies aimed at improving digital infrastructure and skills. DESI also serves as a tool for governments to make informed decisions and set specific goals for digital transformation, and contributes to increasing the competitiveness of Member States and supports the development of digital innovation and capacities.

**DESI methodology**

DESI is structured into five main dimensions, which include various subcategories and specific indicators:

1. **Digital Skills**: Assesses the level of digital skills among the population and includes both basic and advanced digital literacy.
2. **Digital Infrastructure**: Assesses the availability and quality of broadband, including mobile broadband and 5G network coverage.
3. **Digital transformation of businesses**: Measures the use of digital technologies in businesses and their integration into business processes.
4. **Digitisation of public services**: Evaluates the level of digitisation of public services and their accessibility for citizens and businesses.

**The Czech Republic in the context of DESI**

As of 2023, a summary assessment for the DESI index has not been processed, and thus an overall comparison of the Czech Republic with other EU states cannot be presented. In previous reports, when the overall comparison was carried out, the Czech Republic achieved results that were somewhat below average in the overall index score. From 2023, it is therefore appropriate to evaluate sub-indicators and individual dimensions rather than DESI as a whole.In terms of human capital and digital skills, the Czech Republic achieves an average level. The proportion of the population with at least basic digital skills is 60%, which is above the EU average. However, the proportion of ICT specialists is slightly below average. In the area of the digitalisation of public services, the Czech Republic is slightly below the EU average, particularly in the area of e-health, where it achieves a significantly lower score than the EU average.

The coverage of households with a very high-speed internet connection (VHCN) in the Czech Republic is significantly below the EU average, mainly due to the low take-up of fibre-optic networks. In 2023, household fibre network coverage stood at just 36%, the third lowest figure in the EU. This shortfall significantly impacts overall digital connectivity and poses a major challenge for further development.

On the other hand, the availability of 5G networks in the Czech Republic exceeded the EU average for the first time in 2023, which is a positive indicator for further digital development. This progress in 5G networks can serve as a basis for improving other aspects of digital infrastructure. Strategic attention and investment in expanding fibre-optic networks and improving VHCN are key to ensuring better digital connectivity and the competitiveness of the Czech Republic in the digital economy.

**Availability of 5G networks in the Czech Republic**

When quantifying the indicator of 5G network availability, DESI relies on an external study whose analysts obtain data on 5G network availability from national regulators; in the case of the Czech Republic, this is the Czech Telecommunications Authority. The latter has developed a detailed measurement methodology for calculating the availability of

5G networks, which sets the parameters for measurements whilst driving (useful for measuring the availability of 5G networks on corridors and motorways) and stationary measurements. Given that data mainly from stationary measurements are not available, coverage simulation is used to calculate the availability of 5G networks. For this purpose, the CTA uses the mathematical model ITU-R P.1812, which simulates signal propagation based on data about base stations. This model includes a detailed analysis of the terrain between the transmitter and the receiver and is suitable for coverage calculations of cellular networks.

According to data processed by the aforementioned coverage simulation, the total availability of 5G networks in the Czech Republic reaches 96.8% of the population, according to CTA data. Among the operators, Vodafone has the highest coverage, with its 5G network accessible to 93.2% of the population, whilst O2, whose 5G network covers only 84.1% of the population, has the lowest coverage. It is possible to disaggregate this data at the level of basic residential units (ZSJ) and thus analyse differences in the availability of 5G connections in the Czech Republic. Such an analysis shows that whilst 100% of the population is covered by a 5G signal in two-thirds of the ZSJ, the availability of connection decreases in rural areas with a lower population density, particularly in the border regions of the Czech Republic. Data on the difference in 5G network availability between urban and rural areas also reflect this. In rural areas, as defined by the DESI methodology, 22% of the Czech Republic's population live (although this accounts for 73% of the country's total area), and 5G network availability in these areas drops to 87.3%. Conversely, in urban areas, more than 99% of the population has access to the 5G network of at least one operator.

5G networks are available in the Czech Republic mainly, with the exception of the operator O2, in the 700 MHz low-frequency band. Although five operators have been granted licences to operate 5G networks in the mid-3.4–3.8 GHz band, the availability of 5G connections in this band has not yet been sufficiently developed. In total, a 5G connection in the mid-band is available to around a quarter of the population (data from June 2024), but there are significant differences between operators. In the case of the O2 operator, a connection in this band is available to more than a fifth of the population of the Czech Republic, whilst in the case of the T-Mobile operator it is only 15% and in the case of the Vodafone operator 1.3%.

**Comparison of 5G network availability with Germany**

In Germany, 5G technology is available across 92% of the country, with a 5G connection available to 99.66% of households. It follows that there are almost no so-called 'white spots' in Germany, i.e. areas without access to 5G networks. Data from the German regulator even suggests that more than 99% of the population has access to a 5G network from more than one operator. Furthermore, there is a significantly high proportion of standalone (SA) 5G networks in Germany, a technology that operates on its own independent 5G infrastructure. This technology covers 89.9% of Germany, and more than 90% of households have access to SA 5G networks. The use of frequency bands is also a key factor. According to DESI data, the availability of 5G networks in higher frequency bands (3.4–3.8 GHz) in 2023 will reach 43.8% of households. Availability continues to be higher in lower frequency bands (700 MHz), which are particularly suitable for covering less densely populated areas due to their greater coverage range.

The level of 5G network coverage in the Czech Republic and Germany is therefore roughly comparable, and in both countries the proportion of households with access to 5G networks is above the EU average. On closer inspection, however, it must be noted that the Czech Republic lags behind Germany in terms of 5G network development. Operators in Germany have already invested heavily in building a new, 'proprietary' 5G network core, which is reflected in the widespread availability of SA technology across the country. In order to roll out 5G services quickly, operators in the Czech Republic have relied on DSS technology, where the 5G network core is shared with the previous generation. Consequently, unlike their German counterparts, all operators in the Czech Republic have yet to make substantial investments in the transition to SA technology. Operators in Germany are currently focusing primarily on expanding the availability of 5G networks in the mid-frequency bands (3.4–3.8 GHz), particularly in urbanised areas, where greater priority must be given to network capacity and other quality parameters. This also entails significant investment in densifying the network of base stations. Coverage in this band exceeded two-fifths of the population in Germany by the end of 2023 and is expected to continue growing. Even in this case, operators in the Czech Republic are lagging behind – although they have held the licence to operate 5G networks in the 3.4–3.6 GHz band since the beginning of 2021, significant investment in the development of coverage in this band has only been made by one operator, and the total proportion of the population with access to the 3.4–3.6 GHz band is therefore only around 25%.

**The future development of 5G network availability in the Czech Republic and trends in the context of DESI**

The key barriers and limitations to the development of 5G networks in the Czech Republic stem from the conclusions outlined above. The main limitation to the development of 5G networks in the Czech Republic relates to the insufficient use of higher frequency bands and the need for investment in SA technology. To improve the quality and capacity of the connection, it will be necessary to increase the proportion of standalone 5G networks and expand the use of the 3.4–3.6 GHz band. In other words, after obtaining licences to operate 5G networks, operators in the Czech Republic focused on the rapid expansion of network coverage itself. The level of population coverage via 5G connections in the Czech Republic is above the EU average, and the scope for further growth is already very limited. In the coming period, however, the key investments will be in improving the quality of 5G networks, and in this area operators in the Czech Republic are lagging behind other EU countries.

The scope for further increasing the coverage of the territory with 5G networks is already rather limited. 96.8% of the population is currently covered by the 5G network signal. This is still a slightly lower share than, for example, in Germany, but within the EU it is, however, an above-average figure. However, further expansion of coverage may already result in disproportionately high investment costs when calculated per person newly covered.

In relation to the Czech Republic's performance in the DESI index, the area of digital infrastructure and connectivity is assessed as below average compared to other EU Member States and in relation to the stated goals of the 'digital decade'. However, this is not due to 5G network coverage – which is above average compared to other EU Member States. The issue for the Czech Republic, as highlighted by the DESI evaluation, is the trend in gigabit connectivity, driven primarily by the indicator for the development of fibre-optic networks. The Czech Republic's relative position will therefore tend to deteriorate in the overall assessment of connectivity. It cannot be assumed that, without fundamental investment in infrastructure, there will be a significant increase in the proportion of households connected to a very fast fixed internet connection in the foreseeable future – the Czech Republic will continue to lag behind in this indicator, whilst the "lead" that the Czech Republic currently holds in the area of 5G network coverage will shrink compared to other EU Member States. Assuming there is no change to the DESI methodology, i.e. the indicators included in this assessment, a trend towards a worsening assessment of the Czech Republic is to be expected.

**Qualitative parameters of 5G network availability in the Czech Republic**

For the analysis of qualitative parameters, there is insufficient robust data on the quality of the connection, so the evaluation must be based on several partial sources. Ad-hoc measurements are taken into account, but their weakness lies in the fact that they are usually commissioned by operators (and published in their media outputs) – and therefore, even if the measurement is carried out using robust technology and by a trusted institution, it is necessary to take into account the distortions caused by, for example, the selection of more favourable locations for measurements from the perspective of the study's contractor. For this reason, other sources were also analysed, such as existing measurement data on motorways and major roads or independent data produced by NetTest users. This application is developed and operated by CTA, so the data is considered reliable.

Of the ad-hoc measurements presented by the operators, O2 is the most active; it carries out measurements in cooperation with the Czech Technical University and claims to achieve significantly better results than the other two operators in terms of quality parameters such as download and upload speeds or latency. The average download speed is said to reach almost 300 Mb/s, which is almost double that of the other two operators. The operator attributes this difference mainly to the fact that, although it has lower population coverage with 5G networks, it is significantly more frequently provided in the 3.4–3.8 GHz frequency band, in which higher speeds and network capacity are achieved. A similar conclusion is also indicated by the measurement results of the NetTest application, which also ranks the O2 operator first in terms of speed and latency, though the gap between it and the other two operators is smaller. However, it is necessary to bear in mind the limitations of the conclusions drawn from the NetTest data analysis, caused by the quality and quantity of available data. According to NetTest data, the average download speed in the Czech Republic reaches over 200 Mb/s, but it is important to note that, to eliminate possible distortions, only measurements taken in areas with very strong signal strength were included. If measurements taken in conditions of poor mobile signal availability had also been included, the result would have been significantly worse.

Conversely, data from measurements on motorways and dual carriageways carried out by CTA staff place the O2 operator last in terms of download speeds. This difference is partly due to the poorer coverage of the 5G network in the case of the O2 operator.

Data from the NetTest application can also be used to some extent to provide an indicative comparison of the difference in connection quality parameters for 5G networks in cities and rural areas. Of course, the difference is significant; according to this analysis, the connection in cities is up to half as fast as in rural areas, and lower latency values are also achieved. At the same time, however, direct proportionality does not apply – the quality of the connection does not decrease in direct proportion to the size of the settlement; other parameters are more decisive (distance from a larger agglomeration, geomorphological characteristics of the territory, etc.). However, it is necessary to point out that the use of data from the NetTest application has limited interpretative possibilities due to the number of data entries that can be included in the analysis, as well as other limitations, mainly related to the fact that the data is generated by the users themselves during a connection test. The results of the analysis thus indicate trends rather than providing robust conclusions.

The connection to 5G networks proves to be more stable and of better quality even in high-load situations (i.e. particularly where there is a high concentration of people) compared to older technologies; however, even with 5G networks, connection quality drops significantly once a certain threshold of user density is exceeded (all the more so when low-frequency bands are used). Operators in the Czech Republic and across Europe are addressing these limitations (whilst at the same time a trend of significant growth in demand for high-quality connections can be observed compared to the past, or in terms of data traffic volumes during events with a high concentration of people) by deploying mobile base stations or significantly enhancing the infrastructure in stadiums, concert halls and other venues where a high concentration of users is regularly expected. However, the full potential of 5G networks for managing such situations can only be realised through the use of 'stand-alone' technology.

**Socio-economic benefits and environmental implications of the development of 5G networks**

The socio-economic benefits of 5G networks are assessed primarily in terms of their impact on gross domestic product (GDP), employment and economic benefits across various sectors.

As early as 2017, the European Commission estimated that in the four key strategic sectors (automotive, healthcare, transport and energy), the annual economic contribution could reach up to EUR 113 billion, with the expected creation of around 23 million job opportunities. Other sources also agree on the significant contribution of the development of 5G networks in terms of GDP and jobs. A 2021 report by the European Court of Auditors, citing estimates by Accenture, for example, states that the deployment and development of 5G networks can contribute up to €1 trillion to total EU GDP in the period 2021–2025 and create or transform up to 20 million jobs. The analyses use a variety of economic models, including input-output modelling that tracks the flow of goods and services between sectors of the economy, and dynamic panel data.

5G technologies offer specific benefits in specific sectors. In agriculture, they can increase yields by up to 25% and reduce water and energy costs. Agricultural benefits include the development of precision farming, increased productivity, reduced costs and positive environmental impacts. The development of 5G networks has the potential to bring significant economic impacts in other sectors as well, to support innovation and improve the quality of life. These benefits are complex and include both direct economic impacts and wider socio-economic effects that contribute to the growth and competitiveness of the European economy.

5G networks bring increased data transmission efficiency, which leads to energy savings per transmission unit. However, overall power consumption may increase due to the need for a dense network of small base stations. Necessary to ensure coverage and capacity, these stations increase the network’s overall energy demand.

In addition to energy aspects, environmental costs are also associated with the production and installation of new equipment, which includes the extraction of raw materials, production and logistics. These processes can lead to higher $CO_2$ emissions and the generation of e-waste. There are also concerns about increased electromagnetic radiation caused by a dense network of small cells, which may lead to restrictions on infrastructure development.

# 1 Introduction

## 1.1 Introduction and objectives of DESI

The Digital Economy and Society Index (DESI) is a key tool of the European Commission for monitoring Member States' progress in digital transformation and, as such, plays an important role in supporting policy-making and investment focused on digital transformation. The key output of this process is the DESI report, which has been published annually since 2014 and provides an overview of digital developments in individual Member States of the European Union. The Index assesses the level of digitalisation based on various criteria and categories, enabling comparison and analysis of progress in the digital economy and society across the EU, whilst identifying shortcomings (at both EU-wide and Member State levels) and providing support for policy-making focused on digitalisation and competitiveness.

Since 2023, the Digital Economy and Society Index (DESI) has not been published in a separate report but, in line with the adopted Digital Decade 2030 programme, has been integrated into the annual Digital Decade Progress Reports. As a result, from the 2023 report onwards, the aggregate DESI index is no longer calculated, but its individual indicators continue to be reported in a similar structure within the aforementioned State of the Digital Decade Report. Thus, where reference is made to the DESI in the following text, we mean the data from the Digital Decade Status Report for 2023 and onwards. In order to maintain the data series, we therefore link the two tools (the only thing that cannot be expressed for 2023–24 is the overall value of the DESI index itself).

According to individual reports and other documents, the DESI objectives can be summarised as follows:

1. Monitoring progress in digital transformation

DESI provides a comprehensive overview of the state of the digital economy and society in individual EU Member States. To this end, DESI collects and analyses data across five main dimensions (connectivity, human capital, use of online services, digital adoption by businesses, and digital public services), thereby enabling detailed monitoring and comparison of digital developments.

2. Identifying shortcomings and areas for improvement

DESI identifies areas where individual Member States are lagging behind and where improvements are needed. In this regard, it produces:

- Weakness analyses: Thanks to detailed statistics and indicators, DESI can pinpoint which areas of the digital economy and society require further investment or reform.
- Identification of disparities: DESI highlights differences between individual Member States, which helps to understand where efforts need to be stepped up to achieve digital convergence across the EU.

3. Support for policy-making and decision-making

The DESI is intended to serve as a tool for informed decision-making by national governments and for setting specific targets and priorities within national digital transformation strategies and European initiatives such as Europe's Digital Decade (see https://digital-strategy.ec.europa.eu/en/policies/digital-decade), which sets out specific targets for digital transformation by 2030.

4. Supporting competitiveness and innovation

The aim of DESI is to contribute to increasing the competitiveness of Member States and the EU as a whole by supporting the development of digital innovation and capabilities. In this regard, it is significant that the index focuses, among other things, on the issue of digital competences (skills), the monitoring and support of which is intended to contribute to improving the qualifications of the workforce. The index also systematically monitors the adoption of digital technologies in both the private and public sectors.

DESI therefore plays a key role within the broader framework of the European Union's digital transformation policy. Key EU policies and initiatives linked to DESI include, in particular:

- Digital Strategy EU / Roadmap to the decade (see https://digital-strategy.ec.europa.eu/en, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en): DESI supports the objectives of the EU's digital strategy, which aims to improve digital infrastructure, skills and innovation.
- Digital Europe Programme (https://digital-strategy.ec.europa.eu/en/activities/digital-programme): This programme funds projects and initiatives aimed at improving digital capabilities and infrastructure in Europe.

- Horizon Europe (https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en): A research and innovation programme that supports projects in the field of digital transformation.
- The Recovery Plan for Europe (https://commission.europa.eu/strategy-and-policy/recovery-plan-europe_en): DESI serves as a guide for investment in digital infrastructure and skills, including under the NextGenerationEU instrument.
- Etc.

**Summary and conclusion**

DESI provides an overview of the state of the digital economy and society in EU Member States and collects data across five main dimensions: connectivity, human capital, use of internet services, digital adoption by businesses, and digital public services. This tool identifies areas requiring improvement and highlights differences between Member States, which aids in the development of policies aimed at improving digital infrastructure and skills. DESI also serves as a tool for informed government decision-making and the setting of specific digital transformation targets, and contributes to increasing the competitiveness of Member States and supports the development of digital innovation and capabilities.

## 1.2 DESI Methodology

The harmonisation and comparability of the data set used to calculate the index are absolutely crucial to its credibility and relevance. This system enables detailed analysis and comparison between countries. The DESI methodology is structured into five main dimensions, which are further divided into several sub-categories and specific indicators, the methodologies for which should be harmonised as much as possible to ensure comparability. Specifically, DESI consists of the following dimensions and indicators[1] :

**1. Digital Skills (formerly: Human Capital)**

This dimension assesses the level of digital skills among the population. It covers both basic digital literacy and the advanced skills necessary for working in the digital economy.

- **Internet usage skills**:
  - (1a1) **Internet usage**: The proportion of people who use the internet at least once a week.
  - (1a2) **At least basic digital literacy**: Measures the percentage of the population with basic or above-basic digital skills across five dimensions (information and data literacy, communication and collaboration, problem-solving, digital content creation, and security)
  - (1a3) **Digital skills above basic level**: Tracks the percentage of the population with digital skills above basic level in the dimensions listed above
  - (1a4) **At least basic digital skills in digital content creation:** The percentage of people with at least a basic level of skills in using software for digital content creation.
  - (1a5) **Enterprises providing ICT training**: The percentage of enterprises that provide ICT training to their employees.

---

[1] The DESI calculation methodology is typically revised annually. The methodology presented here is for 2023, which was the most up-to-date at the time of the analysis. The DESI methodology for 2024 was published in July 2024. Notwithstanding the above, the methodology for 2024 does not take into account indicators 1a5, 1a6, 1b3, 3c3 and 4a4. Conversely, it adds the following indicators to the index:

- Sub-area ‘fixed broadband’ (2a):
  - Total internet access – proportion of households with internet access at home
- Sub-area ‘mobile broadband’ (2b):
  - 5G network coverage in the 3.4–3.8 GHz band – proportion of populated areas where 5G connectivity is available in the specified band
  - 5G SIM cards – proportion of mobile connections to 5G networks relative to the population, expressed as the number of SIM cards that have recorded internet traffic on a domestic 5G network in the last 90 days
  - Edge nodes – number of nodes providing latency of less than 20 milliseconds
- Sub-area ‘digital technologies for businesses’ (3b):
  - AI, cloud technologies or data analytics – the proportion of businesses that use AI technologies, purchase sophisticated cloud computing services or carry out data analytics
  - ‘Unicorns’ – the number of companies falling within the ‘unicorn’ category as defined in Decision (EU) 2022/2481 (Article 2, paragraphs 11(a) and 11(b))

   - (1a6) **Women with at least basic digital skills:** Measures the percentage of the population – women with basic or above-basic digital skills across the five dimensions listed in 1a2
- **Advanced skills and development**:
   - (1b1) **ICT professionals**: The percentage of the workforce comprising specialists in information and communication technologies (defined on the basis of the ISCO-08 classification) out of all employed persons aged 15–74.
   - (1b2) **ICT graduates**: Percentage of graduates in ICT fields out of all graduates.
   - (1b3) Female **ICT specialists:** Percentage of the workforce comprising female ICT specialists out of all ICT specialists.

**2. Digital infrastructure (formerly: Connectivity)**

This dimension assesses the availability and quality of broadband connectivity in EU Member States. Effective connectivity is the foundation of the digital economy, and therefore several aspects of broadband connectivity are measured.

**Subcategories and indicators:**

- **Fixed broadband**:
   - (2a1) **Take-up of fixed broadband connections with speeds of at least 100 Mbps**: The percentage of households subscribing to fixed broadband connections with speeds of at least 100 Mbps, calculated as total broadband take-up multiplied by the percentage of fixed broadband lines with speeds of at least 100 Mbps
   - (2a2) **Take-up of connections with speeds of at least 1 Gbps**: The percentage of households subscribing to fixed broadband connections with speeds of at least 1 Gbps, calculated as total broadband take-up multiplied by the percentage of fixed broadband lines with speeds of at least 1 Gbps
   - (2a3) **Very High Capacity Fixed Network (VHCN) coverage:** The percentage of households covered by any fixed VHCN. The technologies considered are FTTH and FTTB for 2017–2018, and FTTH, FTTB and Cable DOCSIS 3.1 for 2019 and onwards.
   - (2a4) **Fibre to the Premises (FTTP) coverage:** Percentage of households covered by FTTH and FTTB
- **Mobile broadband:**
   - (2b1) **Mobile broadband usage**: Percentage of people using the internet on a mobile device (proportion of people with a mobile data subscription)
   - (2b2) **5G network coverage**: Percentage of populated areas covered by at least one mobile 5G network[2] .
   - (2b3) **5G spectrum:** Amount of spectrum allocated and ready for use by 5G networks within the so-called 5G pioneer bands. These bands are 700 MHz (703–733 MHz and 758–788 MHz), 3.6 GHz (3400–3800 MHz) and 26 GHz (1000 MHz within 24250–27500 MHz). All three spectrum bands are given equal weight.

**3. Digital transformation of enterprises (formerly: Integration of digital**

**technologies) Subcategories and indicators:**

- **Digital intensity:**
   - (3a1) **SMEs with at least a basic level of digital intensity**: Calculated using the so-called digital intensity score, which counts how many of the selected 12 technologies are used by the enterprise. A basic level of digital intensity is achieved if at least 4 technologies are used.
- **Digital technologies for businesses:**
   - (3b1) **Electronic information sharing**: Percentage of enterprises using an ERP (Enterprise Resource Planning) software package to share information across different functional areas (e.g. accounting, planning, production, marketing).
   - (3b2) **Social media**: The percentage of enterprises using two or more of the following social media platforms: social networks, a corporate blog or microblog, websites for sharing multimedia content, and wiki-based knowledge-sharing tools. The use of social media means that the enterprise has a user profile, account or user licence, depending on the requirements and type of social media.
   - (3b3) **Big data**: Percentage of enterprises analysing big data from any data source.
   - (3b4) **Cloud technologies:** The percentage of businesses purchasing at least one of the following cloud computing services: enterprise database hosting, accounting software applications, CRM software, computing power
   - (3b5) **Artificial intelligence:** Percentage of businesses using any AI technology
   - (3b6) **Electronic invoices:** Percentage of businesses sending e-invoices suitable for automated processing
- **E-commerce:**

[2] In practice, however, the indicator reports the proportion of households, not the proportion of the territory.

- (3c1) **Small and medium-sized enterprises selling online**: The percentage of small and medium-sized enterprises (SMEs) that sell online.
- (3c2) **E-commerce turnover:** Total turnover of small and medium-sized enterprises from e-commerce as a proportion of total SME turnover
- (3c3) **Cross-border online sales**: Percentage of SMEs selling online to other EU countries.

**4. Digitalisation of public services**

The digital public services dimension assesses the level of digitalisation of public services and their accessibility to citizens and businesses.

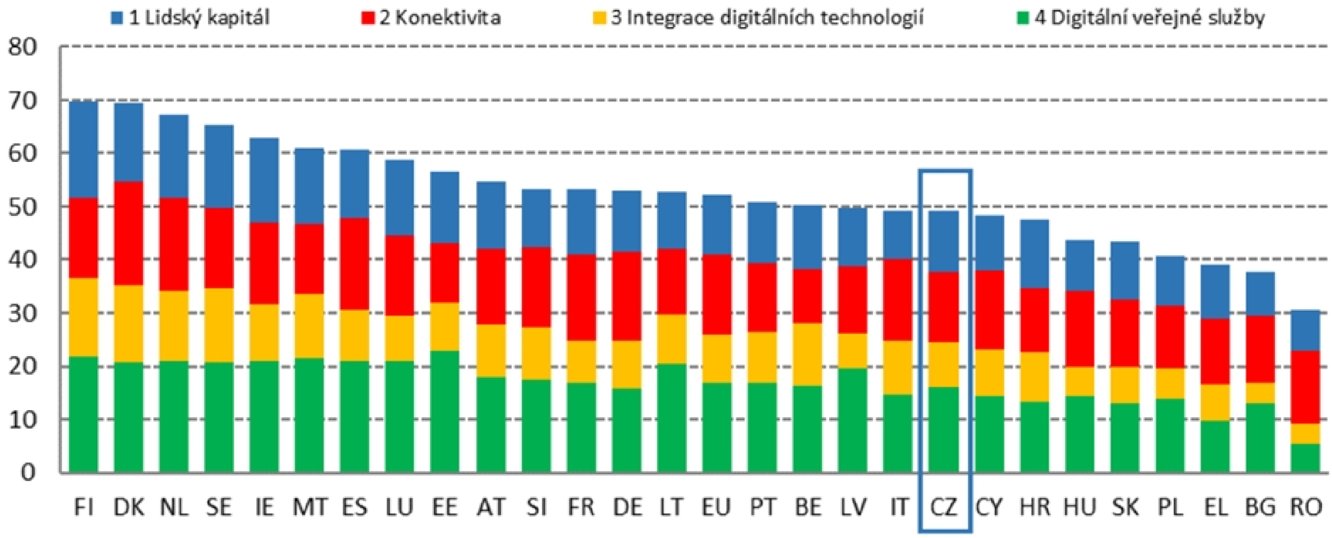
- **E-government**:
  - (4a1) **E-government users:** Individuals who have used the internet in the last 12 months to interact with public authorities via websites or mobile apps – as a % of all internet users
  - (4a2) **Digital public services for citizens:** The proportion of administrative procedures that citizens can complete online for significant life events (birth of a child, change of address, etc.).
  - (4a3) **Digital public services for businesses**: Assessment of the availability of digital services for businesses.
  - (4a4) **Use of e-government services**: Percentage of citizens who use e-government services. The indicator generally reflects the proportion of public services required to start a business and carry out routine business operations that are available online to both domestic and foreign users. Services provided via the portal receive a higher score; services that merely provide information (but must be completed offline) receive a lower score.
  - (4a5) **Pre-filled forms:** The amount of data that is pre-filled in public online forms
  - (4a6) **Transparency of services provided, their design and personal data:** The extent to which service processes are transparent, services are designed with user involvement, and users have control over their personal data
  - (4a7) **User support:** The extent to which online support, help functions and feedback mechanisms are available, including in a cross-border context
  - (4a8) **'Mobile friendliness':** The extent to which e-government services are provided via a mobile interface, an interface that responds to mobile devices.
- **E-health:**
  - (4b1) **Access to electronic health records (e-Health records)**: Measured as: (i) nationwide availability of online services for citizens to access data from their electronic health records (via a patient portal or mobile app for patients), with additional measures enabling access to data for certain categories of people (e.g. carers of children, people with disabilities, the elderly), and (ii) the percentage of people who are able to obtain or use their own minimum set of health-related data currently stored in public and private electronic health record (EHR) systems.

## 1.3 The Czech Republic in the context of DESI

The Czech Republic's scores in the DESI are somewhat below average, placing it in the lower half of the rankings compared to other EU Member States. According to the comparison presented in the 2022 DESI report[3] , the Czech Republic ranked 19th out of 27 EU Member States in the overall assessment and thus also lags behind some other countries in Central and Eastern Europe, such as Slovenia, Lithuania, Latvia and, of course, Estonia.

[3] No such comparison has been produced for 2023; rather, overall DESI scores are not calculated, and individual sub-indicators are evaluated instead.

*Chart 1: Ranking by overall DESI score for 2022*

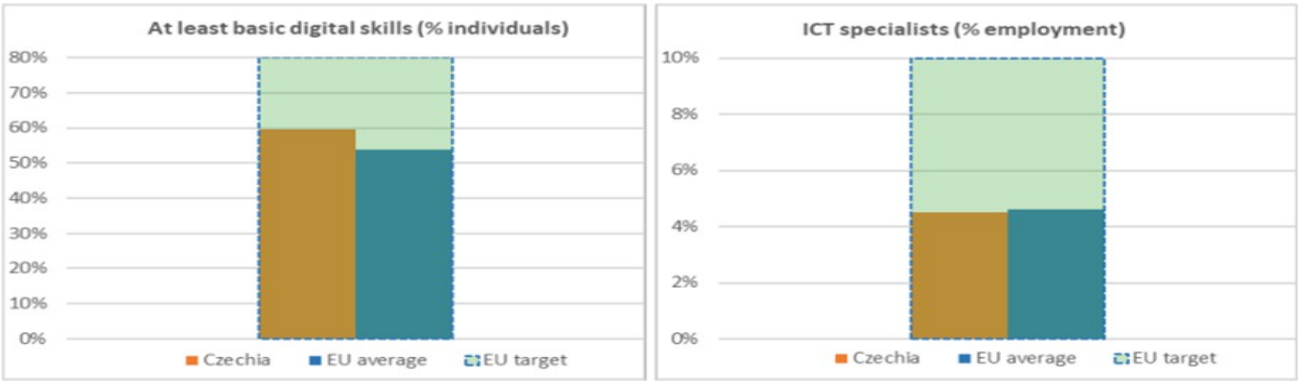



*Source: National DESI Report, 2022*

Overall, the subsequent report for 2023 also states that "the Czech Republic still has underutilised digital potential that could contribute to the joint achievement of the EU's Digital Decade goals" (see Digital Decade Country Report 2023: Czechia – Report on the state of the Digital Decade 2023, COM(2023)570 final: 12). However, the report also notes that the rate of growth in the overall DESI score is faster than in the EU as a whole and is stronger than the EU average, meaning that convergence is taking place, at least in part.

The chart above shows that the Czech Republic achieves its best results in the human capital dimension, specifically digital skills, where the overall score matches the EU average. The level of some indicators quantifying digital skills/human capital in the Czech Republic's digitalisation even exceeds that of the EU as a whole. One example is the indicator of the proportion of the population with at least basic digital skills, where the figure of 60% for 2023 in the Czech Republic exceeds the EU average by approximately 6 percentage points. Conversely, the proportion of ICT specialists in the total workforce is slightly below average, being approximately 0.1 percentage point lower than in the EU as a whole:

*Figure 2: Comparison of selected indicators in the Digital Skills / Human Resources dimension – Czech Republic and EU*

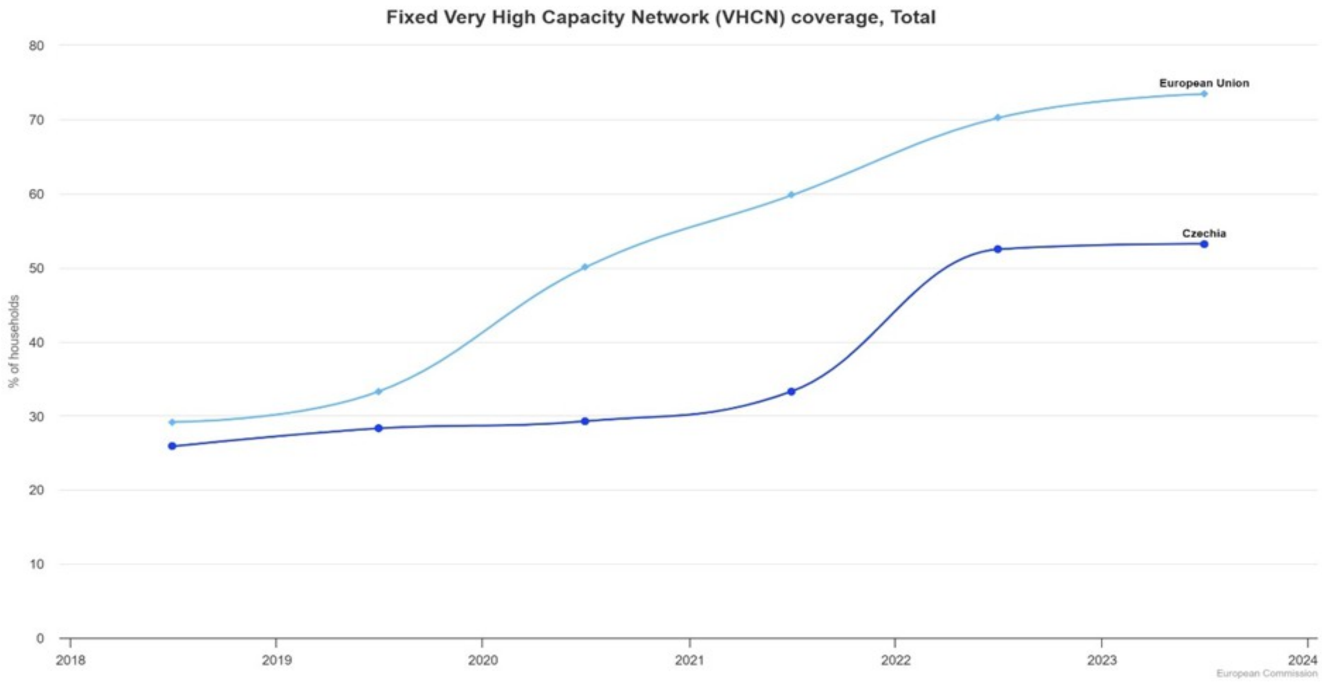



*Source: Digital Decade Country Report 2023 – Czech Republic*

The shortage of information and communication technology specialists in the labour market is cited as one of the key barriers to digital transformation and economic development in general – across all sectors (public, private and academic).

Conversely, the Czech Republic achieves the relatively lowest scores compared to the EU as a whole in the area of connectivity, or digital infrastructure. It is precisely this lag behind other EU countries in this dimension that is the main reason for the Czech Republic's relatively low overall ranking in the DESI index. This is also noted in the 2023 report, which states that the Czech Republic is making very limited progress, particularly in the area of fixed broadband internet access, and that this lag may jeopardise the Czech Republic's ability to contribute to the achievement of the Digital Decade's goals. The proportion of households with access to very high-capacity fixed networks in the Czech Republic stands at only 53% (with a year-on-year increase of just 1 percentage point), which is approximately 20 percentage points below the EU average. It can be observed, however, that the trend for this indicator is not uniform – the trajectory is almost constant with the exception of 2022, when there was a sharp increase of almost 20 percentage points. In the EU as a whole, a steady upward trend can be observed.

*Figure 3: Comparison of the trend in the indicator of household coverage by very high-capacity fixed networks – Czech Republic and EU*

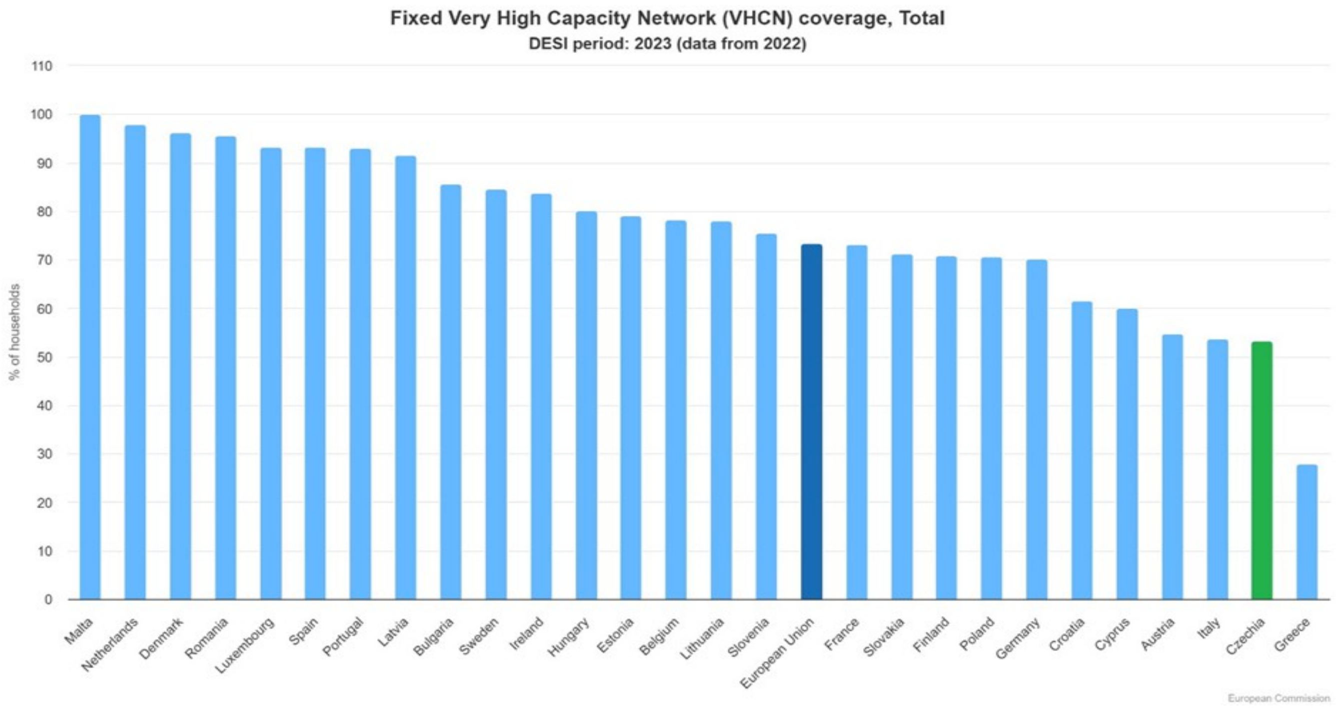



*Source:* [https://digital-decade-desi.digital-strategy.ec.europa.eu/](https://digital-decade-desi.digital-strategy.ec.europa.eu/)

The difference is even greater when looking more closely at the gap between urban and rural areas, where in the Czech Republic approximately 8% of households in rural areas have access to a fixed network with very high capacity, whilst the EU average stands at 45% of households.

The Czech Republic thus ranks second-to-last among all EU Member States in this key DESI indicator (ahead of Greece; the Czech Republic's ranking remains the same when looking more closely at rural areas):

*Figure 4: Values of the indicator for household coverage by very high-capacity fixed networks in EU Member States – 2023*

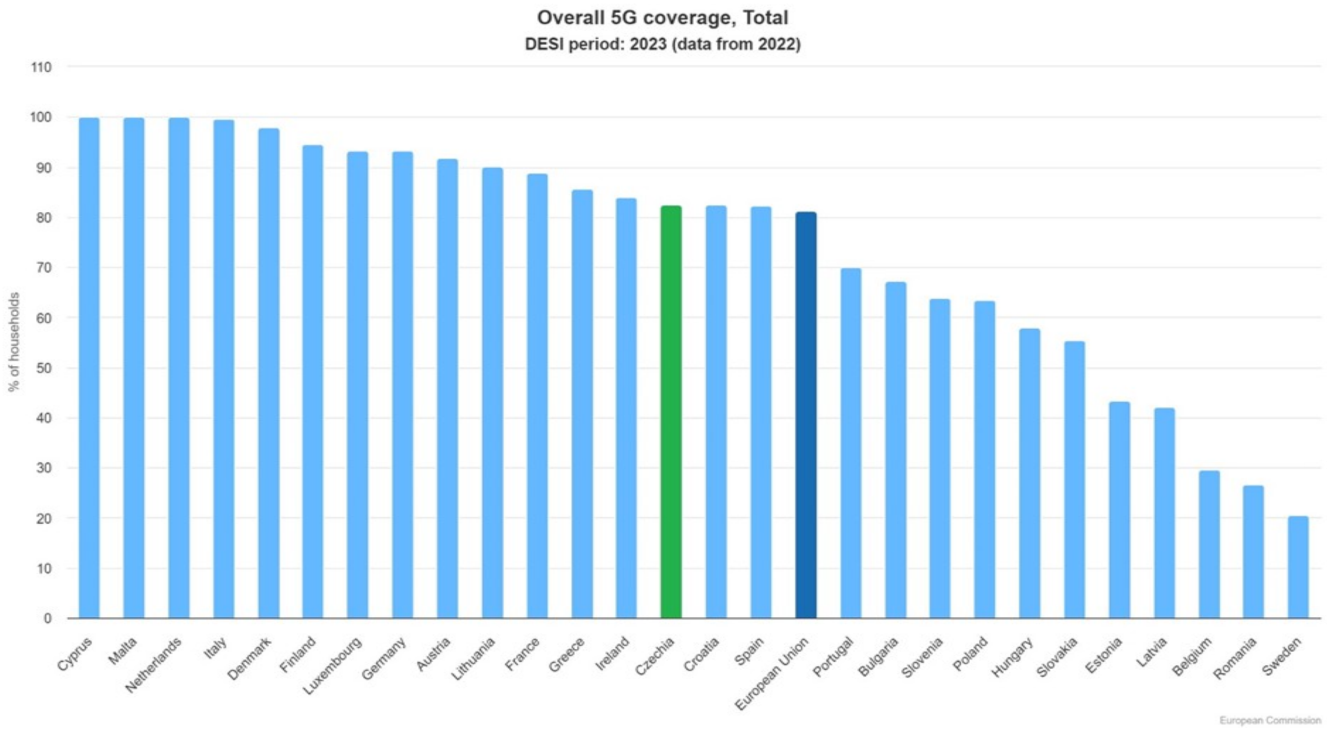



*Source:* [https://digital-decade-desi.digital-strategy.ec.europa.eu/](https://digital-decade-desi.digital-strategy.ec.europa.eu/)

Similarly, the values for other specific DESI indicators assessing access to fixed broadband internet are, understandably, below average. Fixed internet connections of at least 100 Mbit/s are used by just under of households with internet access, and in the case of connections reaching at least 1 Gbit/s, the figure is just 1.3% of households; the EU average stands at 55% and 13.8% respectively.

Conversely, 5G mobile internet coverage is slightly above the EU average: up to 83% of households are located in areas with 5G coverage from at least one operator, whilst the EU average stands at 81%.

*Chart 5: 5G network coverage in EU Member States*




*Source: Comparison of current indicator values in the Digital Infrastructure/Connectivity dimension in the Czech Republic and the EU*

The proportion of people (aged 16–74) using mobile broadband internet access in the Czech Republic is roughly average (85.4 % compared to the EU average of 86.5%), but the differences between EU Member States are very small for this indicator (Bulgaria has the lowest figure at just under 75% of the population, and in 24 of the 27 EU Member States this figure is higher than 80%).

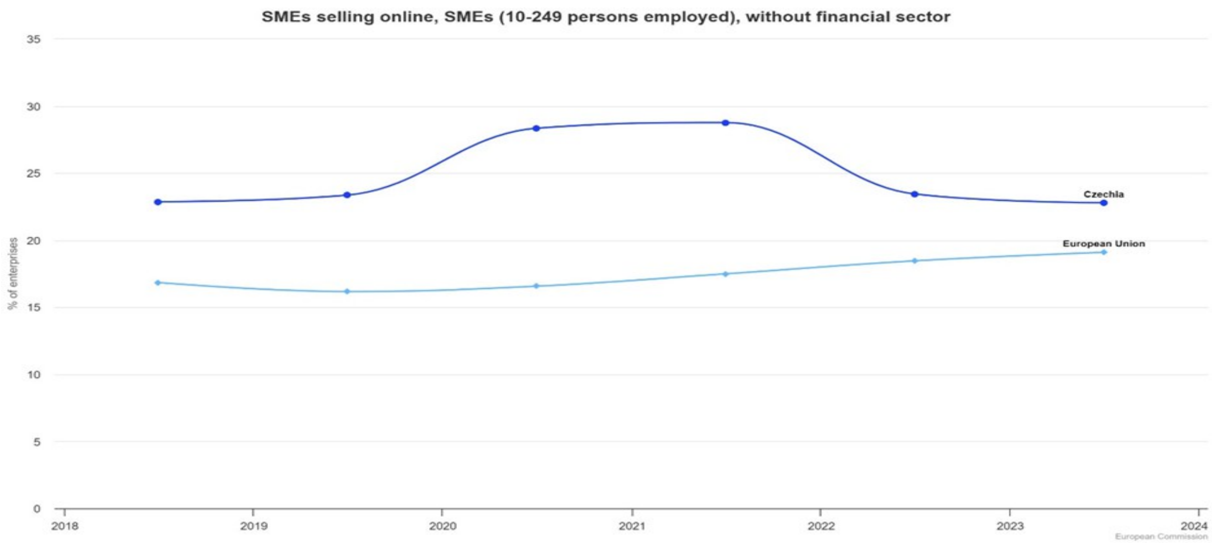
The following table provides an overall comparison of the Czech Republic's figures in this key DESI dimension (in which, however, the Czech Republic lags significantly behind the EU average):

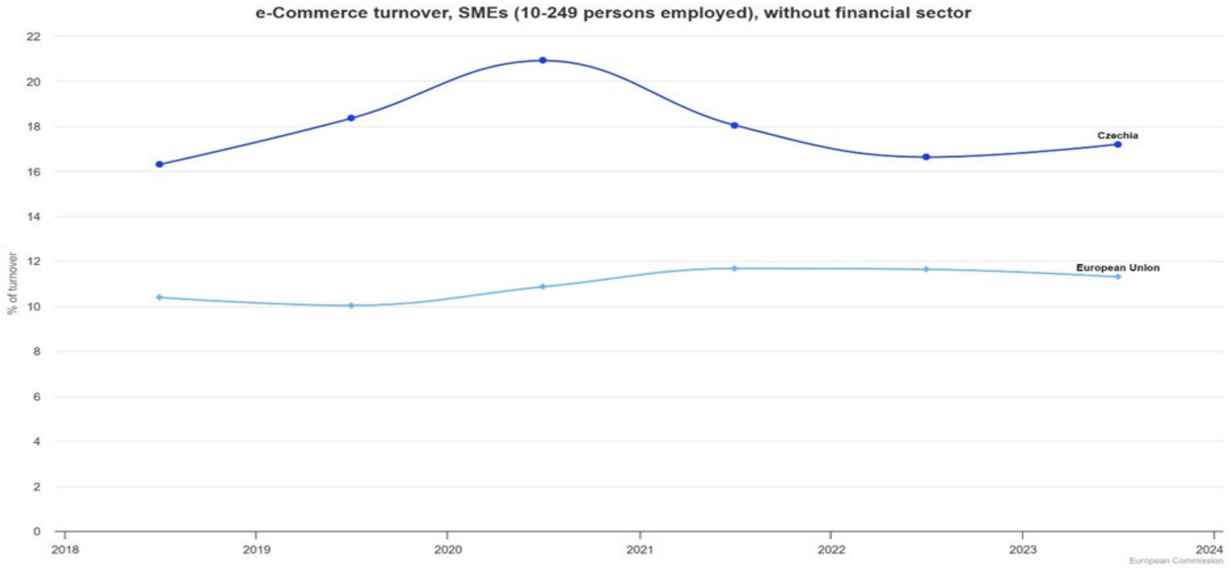
| | Czechia DESI 2021 | Czechia DESI 2022 | Czechia DESI 2023 | EU DESI 2023 | EU 2030 target |
|---|---|---|---|---|---|
| **2a1 At least 100 Mbps broadband take-up** | **26%** | **28%** | **31%** | **55%** | |
| % households | 2020 | 2021 | 2022 | 2022 | |
| **2a2 At least 1 Gbps broadband take-up** | **0.3%** | **0.8%** | **1.3%** | **13.8%** | |
| % households | 2020 | 2021 | 2022 | 2022 | |
| **2a3 Fixed Very High Capacity Network (VHCN) coverage** | **33%** | **52%** | **53%** | **73%** | **100%** |
| % households | 2020 | 2021 | 2022 | 2022 | |
| **2a4 Fibre to the Premises (FTTP) coverage** | **33%** | **36%** | **37%** | **56%** | |
| % households | 2020 | 2021 | 2022 | 2022 | |
| **2b1 Mobile broadband take-up** | **78%** | **85%** | **85%** | **87%** | |
| % individuals | 2018 | 2021 | 2021 | 2021 | |
| **2b2 Overall 5G coverage** | **0%** | **49%** | **83%** | **81%** | **100%** |
| % populated areas | 2020 | 2021 | 2022 | 2022 | |
| **2b3 5G spectrum** | **67%** | **67%** | **67%** | **68%** | |
| Assigned spectrum as a % of total harmonised 5G spectrum | 2021 | 2022 | 2023 | 2023 | |

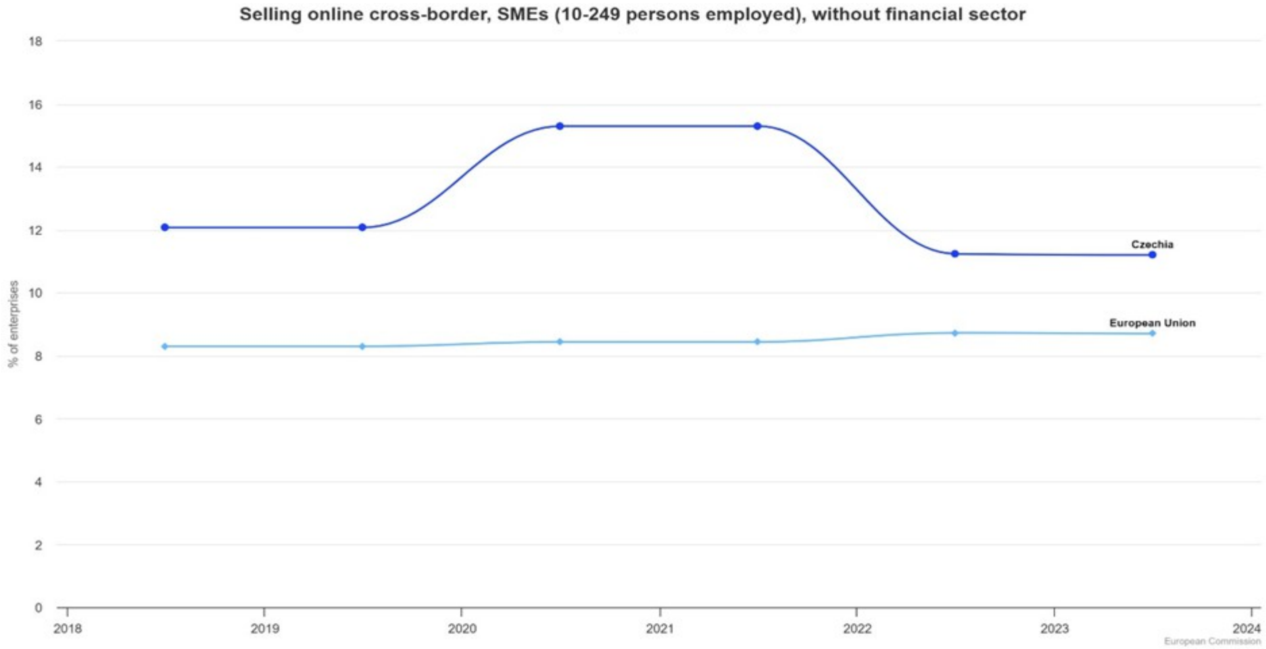
*Source: Digital Decade Country Report 2023 – Czech Republic*

The Czech Republic also achieves below-average scores compared to the EU in two other DESI dimensions. In the area of digital technology integration, or digital transformation of businesses, the Czech Republic ranked 19th among EU Member States, according to the 2022 report. However, the gap from the EU average for this dimension is relatively small. This is also evidenced by the fact that, for most sub-indicators, the Czech Republic achieves similar or even higher values than the EU average. It lags significantly behind only on the indicator for the use of big data (9% of enterprises in the Czech Republic, 14% in the EU) and the use of electronic invoices (12% in the Czech Republic, 32% EU average; the Czech Republic is second from the bottom in this sub-indicator – ahead of Bulgaria). It is also interesting that the Czech Republic achieves above-average values for all three sub-indicators in the area of e-commerce; for the indicator of the share of turnover from e-commerce, it even records the third-highest value in the EU as a whole (17.2% of turnover – behind Ireland with 26.2% and Denmark with 18.9%). However, in the case of this group of indicators, it is also necessary to point out that, compared to the previous period, they all show a decline. Whilst this can be partly explained by a return to 'normal' following the disruption caused by the COVID-19 pandemic, when a significant proportion of businesses were able to strengthen their online operations, the data for the EU as a whole do not follow this trend and show a steady or positive trend even in the post-COVID period. Even when compared with other EU countries, such a marked fluctuation (i.e. a significant increase in the 2021–2022 period followed by a decline to the previous level) is observed only in isolated cases (e.g. Romania, and to a lesser extent Denmark or Ireland).

*Figure 6: Comparison of trends in sub-indicators within the e-commerce group – Czech Republic and EU*






In the case of the digitalisation of public services dimension, the Czech Republic's overall score is again slightly below average, though the differences from the EU average are often rather small. The main exception is the area of e-health (newly introduced for DESI 2023), in which the Czech Republic achieves a score of 47 points out of 100, whilst the EU average is 72 points (the Czech Republic again ranked second-to-last among the assessed countries in this indicator, ahead of Slovakia). However, the Czech Republic also scores significantly below average in terms of user support and pre-filled forms. Conversely, however, there is a significantly higher proportion of e-government users (86%) than the EU average (74%; the Czech Republic's figure is close to the median, as the EU average is significantly skewed downwards due to very low figures in Romania and Bulgaria – 23.5% and 31.7% respectively).

An overall comparison of the Czech Republic and the EU is presented in the table below:

| | Czechia | | | EU | EU |
|---|---|---|---|---|---|
| | DESI 2021 | DESI 2022 | DESI 2023 | DESI 2023 | 2030 target |
| **4a1 e-Government users**<br>% internet users | NA | NA | 86%<br>2022 | 74%<br>2022 | |
| **4a2 Digital public services for citizens**<br>Score (0 to 100) | NA | 75<br>2021 | 76<br>2022 | 77<br>2022 | 100 |
| **4a3 Digital public services for businesses**<br>Score (0 to 100) | NA | 81<br>2021 | 84<br>2022 | 84<br>2022 | 100 |
| **4a4 Pre-filled forms**<br>Score (0 to 100) | NA | 41<br>2021 | 42<br>2022 | 68<br>2022 | |
| **4a5 Transparency of service delivery, design and personal data**<br>Score (0 to 100) | NA | 54<br>2021 | 57<br>2022 | 65<br>2022 | |
| **4a6 User support**<br>Score (0 to 100) | NA | 67<br>2021 | 68<br>2022 | 84<br>2022 | |
| **4a7 Mobile friendliness**<br>Score (0 to 100) | NA | 81<br>2021 | 80<br>2022 | 93<br>2022 | |
| **4b1 Access to e-health records**<br>Score (0 to 100) | NA | NA | 47<br>2022 | 72<br>2022 | 100 |

*Source: Digital Decade Country Report 2023 – Czech Republic*

An overview of trends in key DESI indicators is provided in the following table (with the exception of access to 5G networks, the table only includes indicators for which a time series of more than two years is available). For most indicators, an upward trend can be observed (green rows in the table below). However, some indicators show stagnation (orange) or even a decline (red). As mentioned above, a stagnating or declining trend can be observed for all indicators describing e-commerce. A negative trend is also evident in some of the indicators capturing the adoption of digital technologies in businesses – primarily electronic information sharing and the use of electronic invoicing.

*Table 1: Long-term trend of DESI indicators in the Czech Republic and comparison with the EU*

| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | EU 2023 | trend (graphic by Ky) |
|---|---|---|---|---|---|---|---|---|
| 1a1: Internet usage | 80.5 | 83.8 | 84.7 | 86.0 | 87.4 | 89.7 | 89 | |
| 1a5: Organisations providing vocational training in the field of ICT | 23.0 | 24.8 | 24.5 | 24.7 | 24.7 | 23.1 | 22 |  |
| 1b1: ICT specialists | 3.6 | 4.0 | 4.0 | 4.2 | 4.6 | 4.5 | 4.6 | |
| 1b2: ICT graduates | 4.0 | 4.5 | 4.9 | 5.0 | | | 4.2 | |
| 1b3: ICT specialist | 10.1 | 9.7 | 10.2 | 10.3 | 10.0 | 10.9 | 18.9 | |
| 2a1: Use of fixed broadband connection with speeds of at least 100 Mb/s | 15.6 | 17.9 | 20.5 | 24.2 | 26.8 | 31.0 | 55 | |
| 2a2: Use of a connection with a speed of at least 1 Gb/s | | | 0.0 | 0.3 | 0.8 | 1.3 | 13.8 | |
| 2a3: Fixed-line coverage with very high capacity (VHCNj | 25.9 | 28.3 | 29.3 | 33.3 | 52.5 | 53.2 | 73 | |
| 2a4: Fibre to the Premises (FTTP) coverage | 25.9 | 28.3 | 29.3 | 33.3 | 35.8 | 37.4 | 56 | |
| 2b1: Use of mobile broadband connections | 66.4 | 78.0 | 78.0 | 78.0 | 85.4 | 85.4 | 87 | |
| 2b2: 5G network coverage | | | | 0.0 | 49.4 | 82.6 | 81 | |
| 2b3: 5G spectrum | | 16.7 | 16.7 | 66.7 | 66.7 | 66.7 | 68 | |
| 3b1: Electronic information sharing | | | 38.0 | 38.0 | 37.7 | 37.7 | 38 | |
| 3b2: Social media | 13.1 | 13.1 | 20.4 | 20.4 | 24.0 | 24.0 | 29 | |
| 3b3: Big Dala | 8.5 | 8.1 | 8.1 | 9.1 | 9.1 | 9.1 | 14 | |
| **3b6: Electronic invoices** | | 14.4 | 14.4 | 12.2 | 12.1 | 12.2 | 32 | |
| 3c1: Small and medium-sized enterprises selling online | 22.9 | 23.4 | 28.4 | 28.8 | 23.4 | 22.8 | 19 | |
| 3c2: E-commerce turnover | 16.3 | 18.4 | 20.9 | 18.0 | 16.6 | 17.2 | 11 | |
| 3c3: Cross-border online sales | 12.1 | 12.1 | 15.3 | 15.3 | 11.2 | 11.2 | 9 | |
| 4a1: E-government users | 53.4 | 61.0 | 61.4 | 63.8 | 75.9 | 86.0 | 74 | |

*Source: own compilation*

**Summary and conclusion**

In 2023, the Czech Republic ranked 19th out of 27 EU Member States in the DESI index, indicating below-average results compared to other EU countries. Although the rate of growth in the DESI score in the Czech Republic is faster than the EU average, it is still not fully utilising its digital potential.

In the human capital and digital skills dimension, the Czech Republic achieves an average level. The proportion of the population with at least basic digital skills is 60%, which is above the EU average. However, the proportion of ICT specialists is slightly below average. In the area of public service digitalisation, the Czech Republic is slightly below the EU average, particularly in the field of e-health, where it achieves a significantly lower score than the EU average.

Coverage of households with very high-speed internet (VHCN) in the Czech Republic is significantly below the EU average, mainly due to the low penetration of fibre-optic networks. In 2023, fibre-optic network coverage of households stood at just 36%, the third-worst figure in the EU. This shortfall significantly impacts overall digital connectivity and presents a major challenge for further development. On the other hand, **the availability of 5G networks in the Czech Republic exceeded the EU average for the first time in 2023**, which is a positive indicator for further digital development. This progress in the area of 5G networks can serve as a foundation for improving other aspects of digital infrastructure. Strategic focus and investment in the expansion of fibre-optic networks and the improvement of VHCN are key to ensuring better digital connectivity and the Czech Republic's competitiveness in the digital economy.

# 2 Methodology for calculating the 5G network availability indicator in the Czech Republic

## 2.1 Methodology for calculating the indicator in DESI

The data source for indicator 2b2 in DESI is the study 'Broadband Coverage in Europe 2022', which is compiled annually by external entities (for 2022, the study was compiled by a consortium of Omdia and Point Topic). The data are therefore reported in the indicator with a one-year lag – the indicator data for 2023 actually reflect the situation in 2022.

According to the methodology of this and previous studies[4] the key source of data for quantifying 5G network coverage (as well as other DESI sub-indicators in the area of digital infrastructure) is a questionnaire survey of national regulators and broadband internet providers and, additionally, an analysis of documents – outputs from national regulators, ISPs and other entities, in particular regulators' reports, annual reports and press releases from ISPs, and other documents published by interest groups and associations, ad hoc analyses, etc.

In other words, in this section, DESI does not carry out its own collection of primary data, but uses data reported by national regulators and internet service providers – in the case of 5G network coverage, therefore, the winners of individual frequency auctions.

The methodologies for calculating data on 5G network availability at national level are therefore key to defining the indicator values.

## 2.2 Methodology for calculating 5G network coverage – ČTÚ

The CTU calculates 5G network coverage using two methods:

1. Measurement of 5G network availability. The ČTÚ distinguishes between two types of measurement: drive-by measurement and stationary measurement. Drive-by measurement is used to measure coverage along linear infrastructure – motorways and corridors. It is also used to measure coverage in municipalities, identify problem areas or resolve customer complaints. Drive-by measurements are also an important method for verifying compliance with auction conditions, known as development criteria[5] . Stationary measurements are primarily used for verification at a specific location in the event of a complaint, typically within a 50x50-metre grid. Stationary measurements are also used to verify development criteria and on an ad-hoc basis to investigate customer complaints. The precise procedure and measurement parameters are defined by the CTO in the document "Methodology for the measurement and evaluation of data parameters of mobile electronic communications networks (…)"[6] .
2. Coverage simulation. This represents a mathematical model that calculates signal propagation. For the simulation, the CTU uses the International Telecommunication Union (ITU-R) P.1812 (Release 5) methodology. This model is the most accurate point-to-area propagation model available within the ITU. It is based on a detailed analysis of the terrain between the transmitter and receiver and incorporates all relevant radio signal propagation models. The model is also suitable for calculations at short distances from the transmitter, which is essential for analysing signal coverage in cellular networks. The CTO performs coverage simulations based on data on base stations provided to the CTO by mobile operators on a monthly basis. Base stations in trial operation are not included in the coverage calculations.

[4] See OMDIA and Point Topic: Broadband Coverage in Europe 2022, 2023, available online: https://ec.europa.eu/newsroom/dae/redirection/document/98574

[5] *Develop development criteria – from auction conditions; monitoring of the CTO's development criteria and a timetable for implementation…*

[6] https://ctu.gov.cz/sites/default/files/obsah/stranky/61086/soubory/metodika-pro-mereni-vyhodnoceni-datovych-parametru-mobilnich-siti-ek-2-3.pdf

When calculating 5G network availability, the second of the above-mentioned approaches is used, namely coverage simulation. One reason for this is that no data on 5G network coverage is currently available from fixed-point measurements – the Czech Telecommunications Office (ČTÚ) has not yet used fixed-point measurements, partly due to a lack of equipment. Data from 5G network availability measurements are therefore currently only available for motorways and corridors.

In addition to the CTO, individual operators also process data on 5G connectivity; the results may differ slightly from the CTO's data (for example, in the past, operators included data on new base stations in their coverage figures, whereas the CTO only includes them after the trial period has ended). This data is not included in this study.

## 2.3 Availability of 5G networks in the Czech Republic

According to data from the Czech Statistical Office (ČSÚ), the overall availability of 5G networks in the Czech Republic reaches 96.8% of the population[7] . Among operators, Vodafone has the highest coverage, with 93.2% of the population able to use its 5G network, whilst O2 has the lowest, with its 5G network covering only 84.1% of the population.

In almost two-thirds of inhabited basic settlement units (BSUs), coverage of 100% of the population is reported. Conversely, less than half of the population is covered by a 5G signal in only 11.4% of BSUs. No coverage is reported in a total of 774 inhabited ZSJs, i.e. 3.5% of all ZSJs. A total of 38,966 inhabitants live in these ZSJs that are not covered by a 5G signal at all (data according to the 2021 Population Census), an average of 50 inhabitants per ZSJ.

These differences can be analysed in more detail in the following table:

| Proportion of residents covered in ZSJ | Number of ZSJs | Total populatio n | Number of residents with access to 5G networks | Average number of residents per ZSJ | Populati on in the service area – maximum | Populati on density (number/km²) |
|---|---|---|---|---|---|---|
| 100% | 14,656 | 8,662,664 | 8,662,664 | 591.1 | 14,784 | 225.1 |
| 90–100% | 2,462 | 1,159,235 | 1,131,055 | 466.7 | 7,460 | 85.2 |
| 75–90% | 1,431 | 264,133 | 219,963 | 180.7 | 4,992 | 41.2 |
| 50–75% | 1,254 | 177,031 | 112,816 | 138.7 | 2,196 | 32.9 |
| 25–50% | 963 | 118,801 | 45,478 | 127.9 | 2,474 | 27.7 |
| 10–25% | 489 | 55,494 | 9,783 | 122.5 | 1,973 | 24.6 |
| Less than 10% | 312 | 47,822 | 2,254 | 156.3 | 1,426 | 27 |
| 0 | 2,021[8] | 38,966 | 0 | 50.3 | 1,134 | 12.5 |

The data above therefore clearly shows that 5G network coverage is poorer in areas with smaller populations and lower population density . Population density is the main explanatory factor; the table above clearly shows that the correlation between the proportion of the population covered (within a given range) and population density is very high.

Differences between operators, logically, also arise when expressing availability at the regional level. Vodafone again achieves the highest coverage, with its 5G signal covering 90.8% of the Czech Republic's territory. T-Mobile is in second place with 83.5% of the territory, whilst O2 currently provides coverage for only 74.5% of the Czech Republic's area. The 5G network of at least one operator is available across 94.8% of the Czech Republic's territory. For further details, see the following cartograms.

[7] Here and below: based on data as at 12 June 2024.

[8] Of these, 1,247 ZSJs are uninhabited; there is therefore zero 5G network coverage in 774 inhabited ZSJs.

**5G network availability per capita**

*Figure 1: Availability of at least one 5G network – population (legend here and below: red: 0%, orange: less than 70%, light green: 70–95 %, medium green: 95–99%, dark green: 99–100%; areas with no population are marked in yellow)*

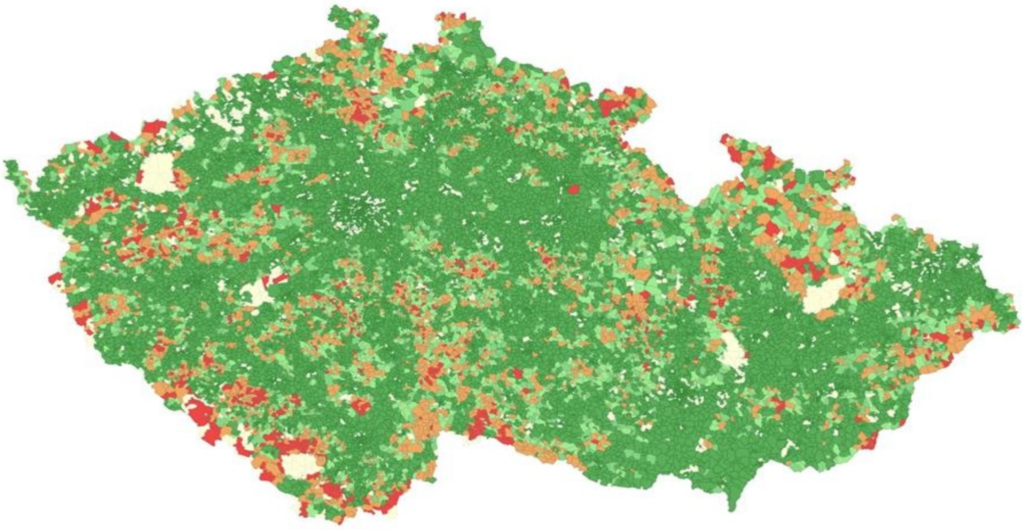
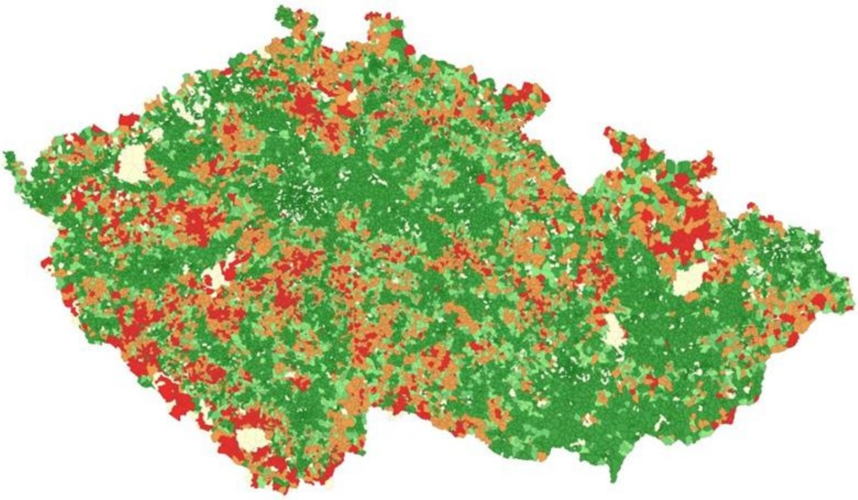


*Figure 2: 5G network coverage for residents: Vodafone*



UNOFFICIAL MACHINE TRANSLATION

*Figure 3: 5G network coverage for residents: T-Mobile*

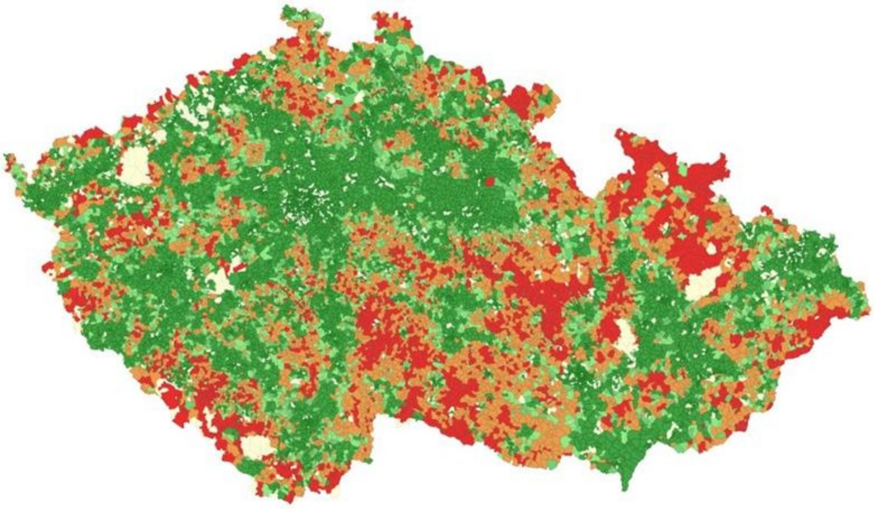
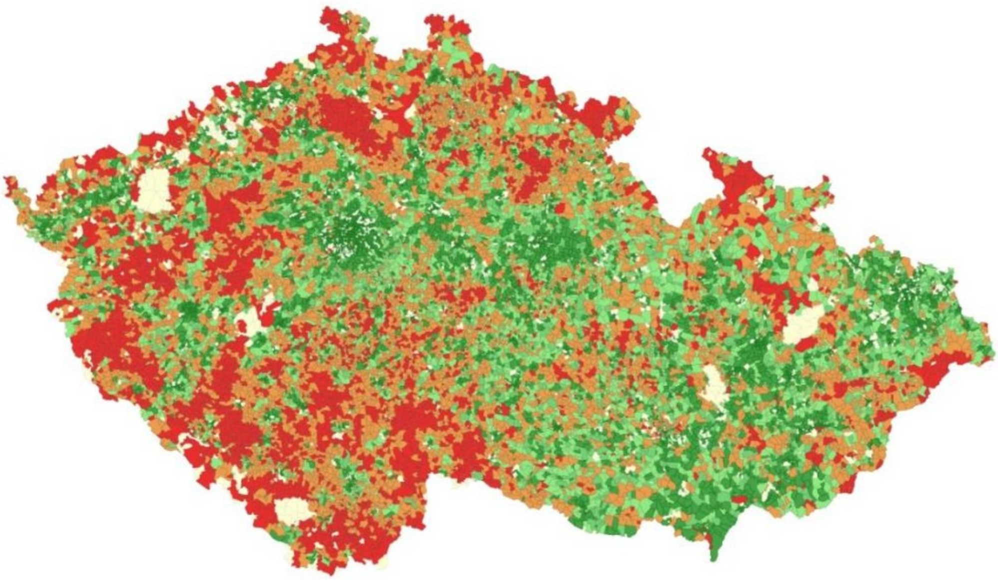


*Figure 4: Availability of 5G networks for residents: O2*



It is clear from the figures above that lower or no availability per capita can be observed primarily in the border regions of the Czech Republic. At the same time, however, it can be seen that the regional distribution of connectivity differs slightly between individual operators. In the case of Vodafone, apart from border areas, insufficient coverage of the population can be observed primarily in western Bohemia, in the north of the Central Bohemian Region, in the area south of the capital city of Prague, or in the Bruntál region; part of this population is covered by T-Mobile's 5G signal. T-Mobile, however, has significant coverage gaps in the Vysočina Region and in the area between Svitavy and Brno. Although O2 has the poorest population coverage and lags significantly behind across almost the whole of Bohemia, with the exception of larger cities and their immediate surroundings, it provides better coverage in some areas of Moravia than the other two operators (e.g. the Bruntál region).

**5G network availability by region**

The definition of 5G network signal availability based on the proportion of covered area is presented in the following cartograms.

*Figure 5: Availability of at least one 5G network – by region*

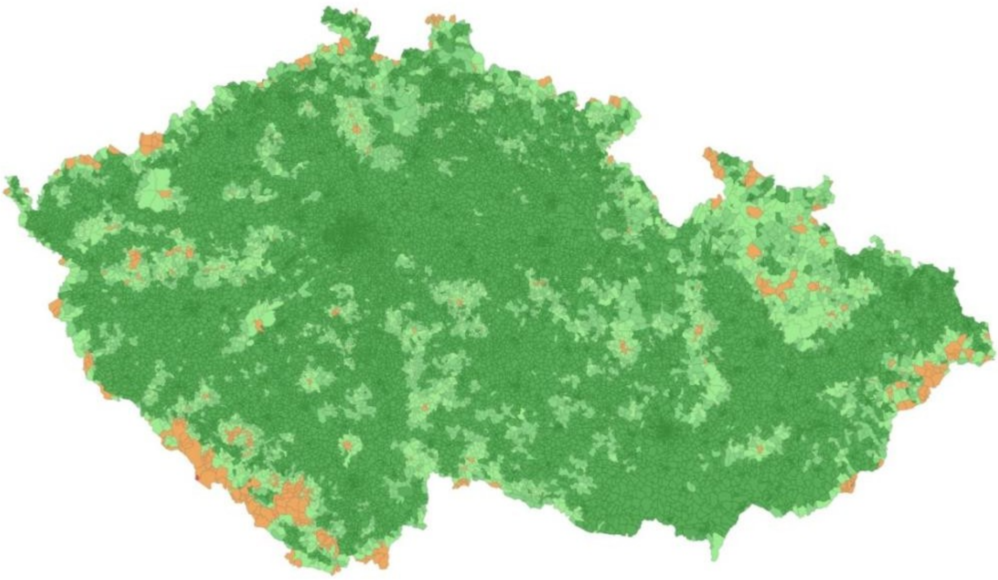


*Figure 6: Availability of 5G networks in the territory – Vodafone operator*

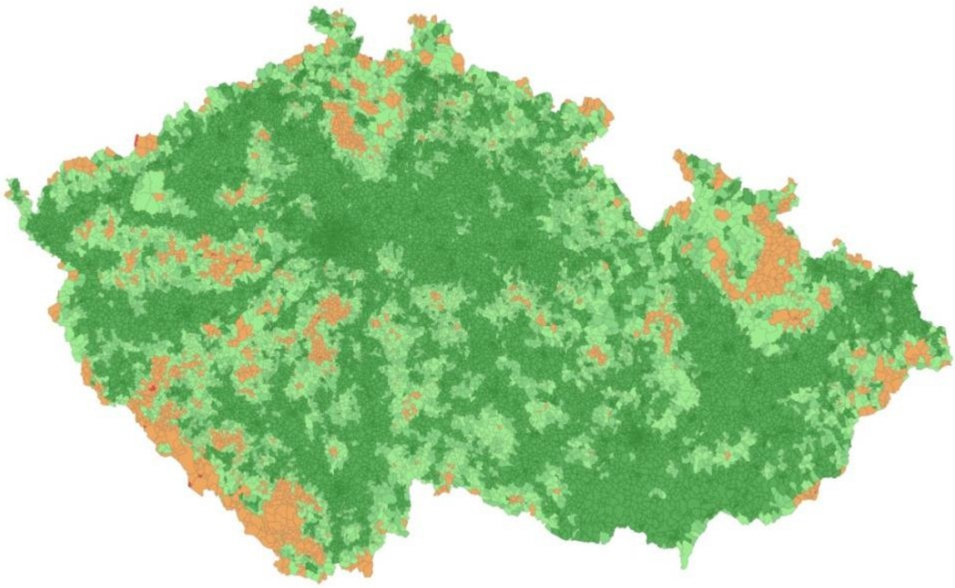


*Figure 7: Availability of 5G networks in the territory – T-Mobile operator*

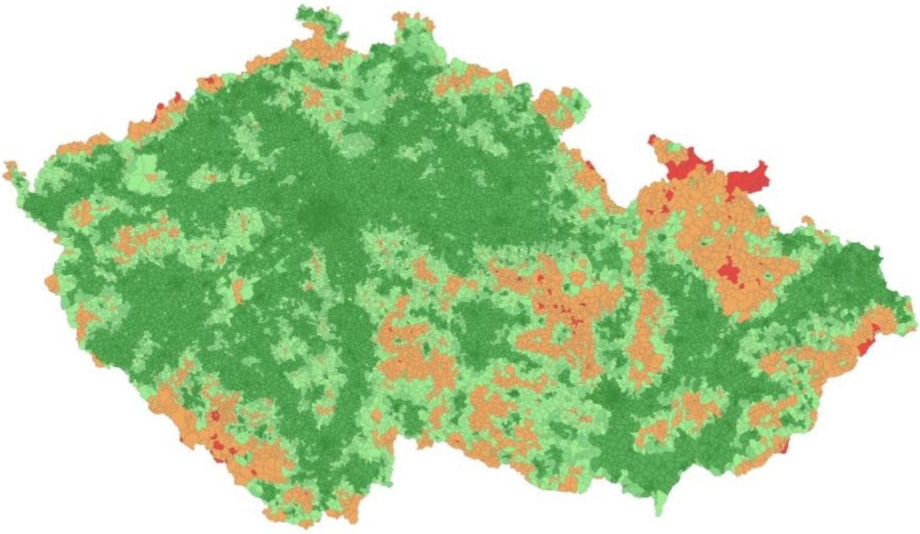
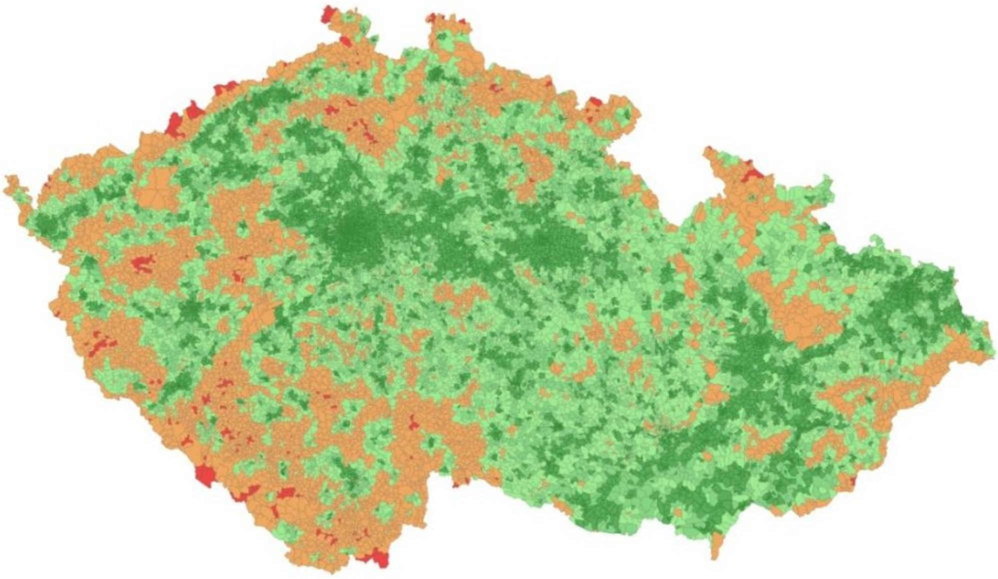


*Figure 8: 5G network coverage by area – O2*



A closer look at the individual frequencies used for the 5G network also reveals significant differences. For example, whilst Vodafone has the highest 5G network coverage in terms of both population and territory, the proportion of this connection in the 3.4–3.8 GHz band is almost negligible – and is currently limited exclusively to larger cities. Conversely, whilst the O2 network currently has the lowest coverage, the roll-out of the network in the 3.4–3.8 GHz band is significantly faster.

According to data from the Czech Telecommunications Office (as of 1 July 2024), the 5G signal in the 3.4–3.8 GHz band currently (June 2024) covers 20.64
% of the population, naturally mainly in larger cities. A slightly higher proportion of the population covered by this operator in the given frequency band can be observed in Moravian cities, but the figures do not differ significantly. In the case of T-Mobile, the proportion of people connected to the 5G network in the 3.4–3.8 GHz frequency band stands at 15.01%, i.e. approximately 5.5 percentage points lower; again, coverage is primarily limited to larger cities. In the case of Vodafone, 5G signal coverage in the 3.4–3.8 GHz band is negligible, with only 1.38% of the population having access to it. It is worth noting that network availability

in this band is rather random – there is no evidence that it is even partially concentrated in cities. For example, in the capital city of Prague, only 4,421 residents, i.e. 0.3%, have access to the 5G network in this frequency band. Overall, therefore, approximately a quarter of the population (25.65%) has access to a 5G network in the 3.4–3.8 GHz band – which enables higher speeds, greater capacity (thanks to bandwidth) and lower latency for internet connections – from at least one operator.

When analysing the difference in 5G network availability between urban and rural areas, we use the definition of rural areas set out in the DESI methodology. This is based on Eurostat data and previous analyses of digital infrastructure availability, and defines rural areas as those with a population density of less than 100 people per km². Whilst in the DESI indicator this binary variable is defined at the NUTS 3 region level (i.e. regions in the context of the Czech Republic), in this study we define rural areas, using the above definition, at the municipal level. The analysis can therefore be significantly more precise.

Under this definition, rural areas will include a territory covering 56,886 km², i.e. 73% of the Czech Republic's total area (calculated excluding military training areas), in which a total of 2.3 million people live, i.e. approximately 22% of the Czech Republic's population. According to data from the Czech Telecommunications Office (ČTÚ), the number of people in municipalities within this rural area who have access to 5G networks is 2,024,266, or 87.3%.

Urbanised areas, according to this definition, account for 27% of the Czech Republic's territory and are home to 78% of the population (8.2 million). The proportion of people in this area with access to 5G networks from at least one operator is 99.1%. This proportion is lowest for O2 customers, whose 5G network covers approximately 91.7% of the population in urbanised areas. For T-Mobile, this proportion stands at 95.4%, and for Vodafone it is as high as 97.1%.

**Summary of the chapter and conclusion**

Data on 5G network availability in the Czech Republic, compiled by the Czech Telecommunications Office (ČTÚ) based on coverage simulations, show that overall 5G network availability in the Czech Republic reaches 96.8% of the population. Among operators, Vodafone has the highest coverage, with 93.2% of the population able to use its 5G network, whilst O2 has the lowest, with its 5G network covering only 84.1% of the population. A more detailed regional analysis at the level of Basic Settlement Units (BSUs) or municipalities shows that whilst 100% of the population is covered by a 5G signal in two-thirds of BSUs, connectivity availability decreases in rural areas with lower population density, particularly in the Czech Republic's border regions. This is also reflected in data on the difference in 5G network availability between urban and rural areas. In rural areas, as defined by the DESI methodology, 22% of the Czech Republic's population lives (although this accounts for 73% of the country's land area), and 5G network availability there drops to 87.3% of the population. Conversely, in urban areas, more than 99% of the population has access to a 5G network from at least one operator.

In the Czech Republic, 5G networks are available, with the exception of the operator O2, primarily in the low-frequency 700 MHz band. Although
five operators have obtained licences to operate 5G networks in the 3.4–3.8 GHz mid-band, 5G connectivity in this band has not yet been sufficiently developed. In total, 5G connectivity in the mid-band is available to approximately a quarter of the population (data as of June 2024), but there are significant differences between operators. In the case of O2, connectivity in this band is available to more than a fifth of the Czech population, whilst for T-Mobile it is only 15% and for Vodafone 1.3%.

# 3 Benchmark: methodology for calculating indicators of 5G network availability according to DESI in a selected EU country (Germany)

## 3.1 Calculation methodology

Data on the availability of mobile services and, more generally, fixed and mobile broadband connections is aggregated by the Federal Network Agency – Bundesnetzagentur (BNA). Detailed data on the availability of 5G network connections is published via an interactive tool on the website https://gigabitgrundbuch.bund.de/ (the so-called Mobilfunk-Monitoring Karte), at a high level of granularity based on a grid of 100x100-metre squares.

When monitoring mobile network coverage, the BNA aggregates coverage at the following levels:

- Territorial coverage (as a percentage of the area of the given territorial unit)
- Household coverage (as a percentage of households with access to the technology in a selected territorial unit)
- Availability along railway corridors (42,000 km), motorways (20,000 km), expressways (Bundesstrasse – 41,500 km), the secondary road network (approx. 180,000 km in length) and waterways (approx. 9,000 km) – as a percentage of the length of the given corridor.

This data is aggregated down to the municipal (Gemeinde) level – with the exception of corridors where the data is processed at the district (Kreis) level. In total, more than 11,000 data points are thus available, the aggregation of which is subsequently used to process data for higher-level administrative units. At this lowest level, the data source is the aforementioned grid of 100 x 100-metre squares.

In addition to the above, the BNA explicitly monitors so-called 'white' and 'grey' spots (weisse Flecken, graue Flecken). A grey spot is an area covered by a 4G or 5G signal from at least one, but not all, operators. A white spot is an area not covered by any operator – meaning that connection to either a 4G or 5G network is not available.

Unlike the Czech Telecommunications Office (ČTÚ), the BNA does not calculate 5G network availability at the individual level; the basic unit in this context is the household. An indicator defined in this way is more consistent with the data collected in DESI, where 5G network availability is also expressed as the proportion of households covered by 5G networks, rather than individuals.

In Germany, the collection of data on the availability of individual mobile technologies is delegated to operators. Under the provisions of the Telecommunications Act (Telekommunikationsgesetz of 23 June 2021, BGBl. I p. 1858), to monitor the availability of individual technologies at the level of defined technologies (see Section 103) and to report this to the BNA in the form of a so-called 'Pegelstabelle', specifically in a 100x100-metre grid[9] on a quarterly basis. The key criterion (which determines whether or not a connection to a given technology at specific frequencies within a designated square is available) is the minimum data transfer rate that can be achieved on a mobile device. However, other situational factors that have a significant impact on the connection at the end device are also taken into account. Furthermore, technical parameters are specified to ensure the comparability of measurements between individual operators – for example, the calculation/measurement must be carried out at a height of 1.5 metres above ground level, and data transfer speed measurements must be processed at

(9) For the complete geographically processed dataset, see https://daten.gdz.bkg.bund.de/produkte/sonstige/geogitter/aktuell/DE_Grid_ETRS89-UTM32_100m.gpkg.zip

at the edges of base station coverage, etc. Last but not least, minimum technical parameters are specified for individual technologies:

*Table 2: Specification of parameters for mobile network coverage and monitoring requirements*

**Vergleich Parametervorgaben**

| | Versorgungs-auflagen | Mobilfunk-Monitoring | | | |
|---|---|---|---|---|---|
| **Technologie** | **technologie-neutral** | **2G** | **4G** | **5G (f < 3 GHz)** | **5G (f > 3 GHz)** |
| Pegelwert [dBm] | Datenrate korreliert mit Pegelwerten | -103 | -109 | | |
| Wahrscheinlichkeit am Zellrand (Pegelberechnung)* | unbeachtlich** | 75% | | | |
| Antennenhöhe [m] | 3 | 1,5 | | | |
| Mindestdatenrate (am Zellrand) | unbeachtlich** | nicht zutreffend | 2 Mbit/s (DL) 512 kbit/s (UL) | 2 Mbit/s (DL) 512 kbit/s (UL) | 5 Mbit/s (DL) 1 Mbit/s (UL) |
| Zellrandwahrschein-lichkeit (Datenrate) | unbeachtlich** | nicht zutreffend | 90% | 90% | 90% |
| Zallauslastung | zelllastunabhängig | nicht zutreffend | 50% | 50% | 50% |
| Mindestdatenrate (Sektor) | 50 Mbit/s bzw. 100 Mbit/s* | nicht zutreffend*** | | | |
| Pegelwert für Ankerband | unbeachtlich** | | | -120 | |

Quelle: Bundesnetzagentur

* Die Datenrate wird auf Basis der Pegelwerte berechnet.
** Bei der Versorgungsauflage wird gemäß PKE geschaut, ob die Netzkapazität bezogen auf eine Fläche zur Verfügung gestellt wird. Die Netzkapazität ist unabhängig von der Nutzung durch Anwender. Daher ist dieser Parameter aus Sicht der Versorgungsauflage irrelevant.
*** Das Mobilfunk-Monitoring fokussiert auf die Nutzerwahrnehmung. Dies wird von mehreren Faktoren, z.B. Lage des Endgeräts in der Funkzelle, Zellauslastung, etc., beeinträchtigt. Daher ist die gesamte Kapazität bzw. Mindestdatenrate (Sektor) aus Sicht des Mobilfunk-Monitoring irrelevant.

*Source: Mobile Communications Report, State of Mobile Coverage 2022*

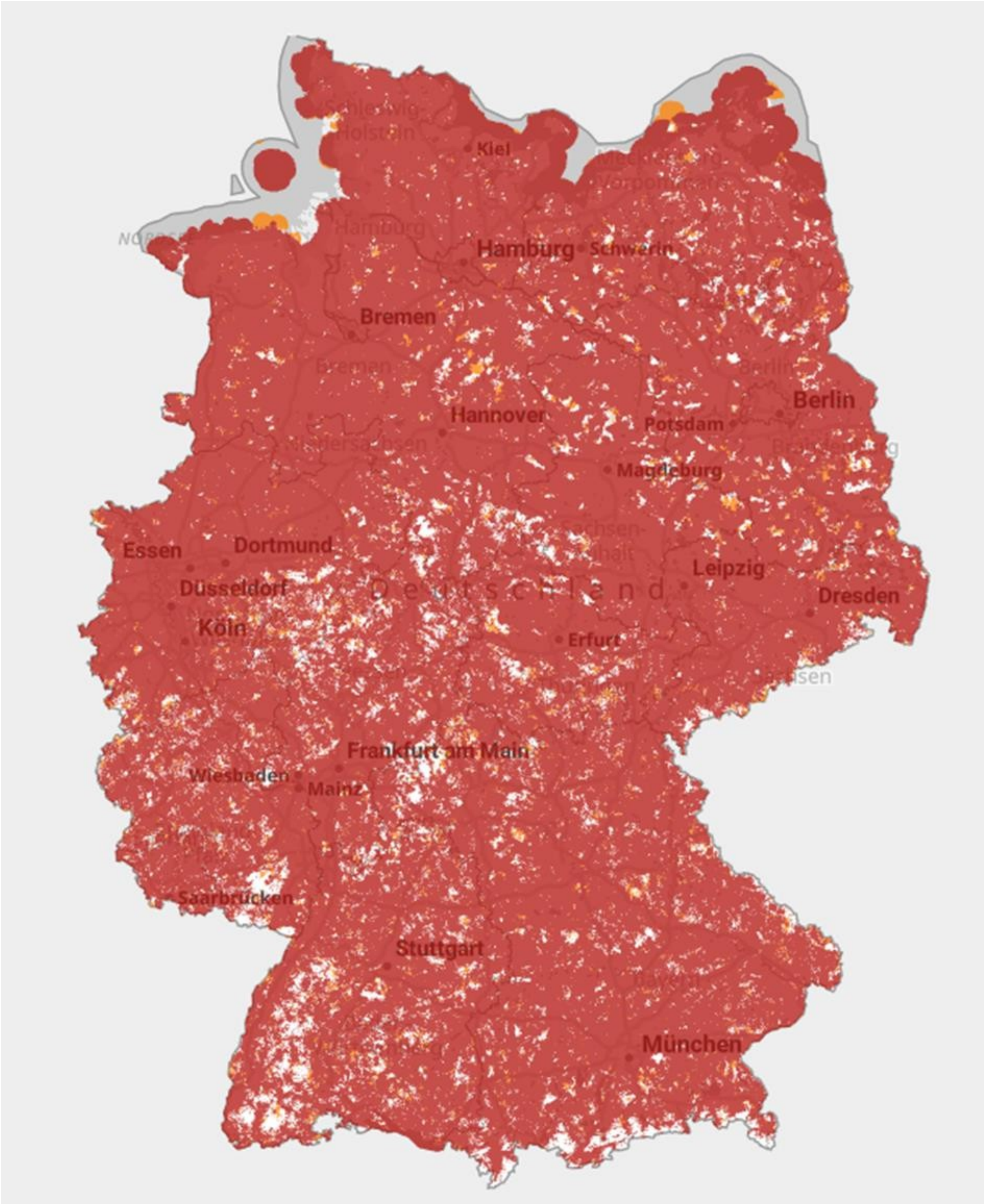
In addition to the data provided by mobile operators, the BNA carries out its own field measurements of signal quality and transmission speeds using special measurement vehicles and mobile devices. The aim of these measurements is to verify the data reported by mobile operators and to identify areas with insufficient coverage or lower service quality.

## 3.2 Current status of 5G network availability in Germany

According to current data (April 2024), 5G technology is available across 92% of Germany. The vast majority of this is 5G Stand Alone (SA) technology – meaning the 5G network operates on its own technology rather than on older technologies (5G SA covers 89.9% of Germany). According to BNA data, 5G network coverage in Germany reaches 99.66% of households. Furthermore, when analysing household coverage, the proportion of 'grey areas' is only 0.68% – meaning the vast majority of households have access to more than one operator providing 4G or 5G connectivity. From this perspective, there are no white spots – all residents of Germany therefore have access to at least one operator providing 4G or 5G connectivity. (From a geographical perspective, 'white spots' are identified in only 2.3% of Germany's territory).

For further details, see the following cartogram

*Figure 9: 5G network coverage in Germany*

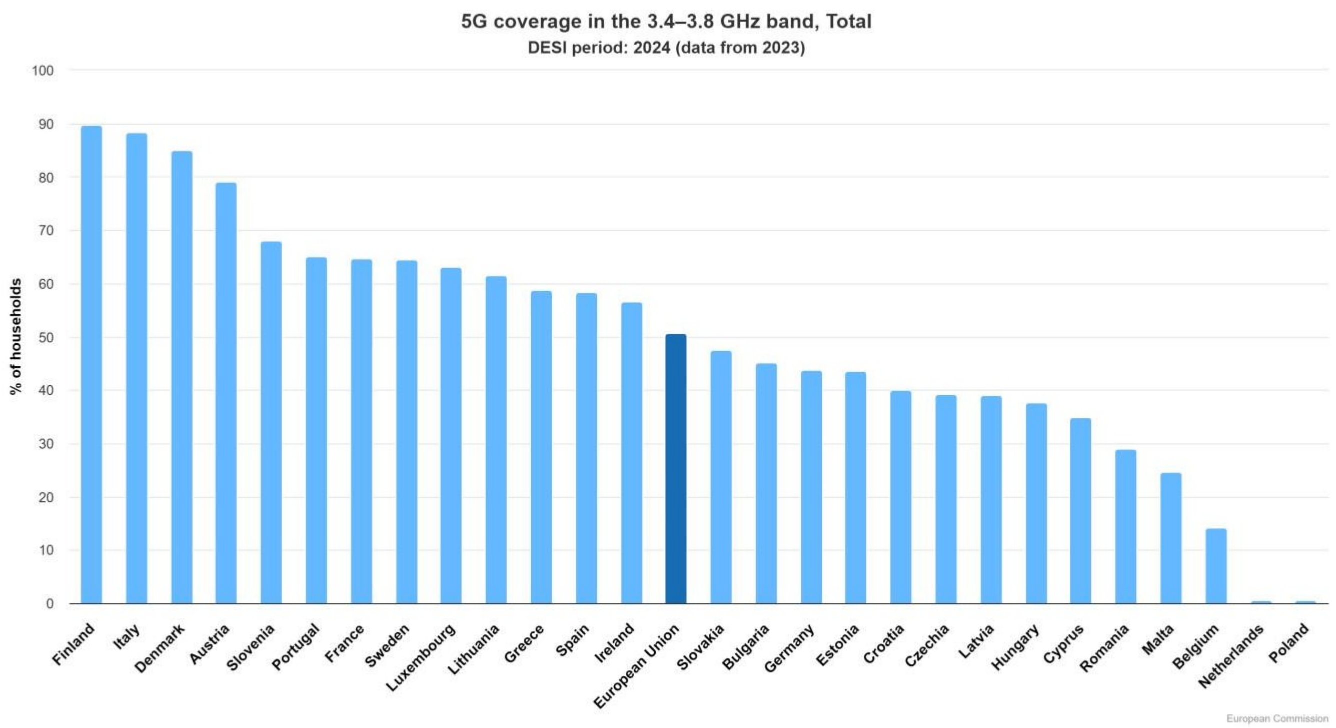



*Legend: red indicates territorial availability of 5G SA, orange indicates availability of 5G only*

*Source: https://gigabitgrundbuch.bund.de*

The use of frequency bands is also an important factor. According to DESI data, 5G network coverage in the higher frequency bands (3.4–3.8 GHz) is projected to reach 43.8% of households by 2023. Availability therefore continues to be dominated by lower frequency bands (700 MHz), which are particularly suitable for covering less densely populated areas due to their greater coverage range (i.e. with fewer infrastructure elements); the proportion of the population covered in higher bands is, logically, concentrated primarily in larger settlements. However, the figure for connectivity availability in higher bands for 2023 is almost on a par with the European average (50.6% of households). Finland has the highest connectivity in these higher frequency bands (89.72%), whilst coverage of 5G networks in the 3.4–3.8 GHz frequency band remains at zero in Poland and the Netherlands.

*Figure 10: Comparison of 5G network availability in the 3.4–3.8 GHz frequency band in the EU (2023)*




*Source: DESI 2024.*

## 3.3 Comparison with the Czech Republic

The level of 5G network coverage in the Czech Republic and Germany is roughly comparable, and in both countries the proportion of households with access to 5G networks is above the EU average. 5G signal coverage in both countries is close to 100% of the population, with gaps remaining only in 'white spots' (2.3% of Germany's land area; in the Czech Republic, the area where no resident has access to a 5G network totals 3.9
% of the territory, excluding uninhabited areas). In Germany, however, there is a significantly higher proportion of households with access to 5G networks in higher frequency bands (3.4–3.8 GHz) – whilst in Germany more than two-fifths of the population had access to 5G networks in this band by the end of 2023, in the Czech Republic this proportion is significantly lower, reaching only around a quarter – though this may be partly due to the higher concentration of the population in large urban areas in Germany. A crucial difference lies in the deployment of standalone (SA) 5G networks, i.e. those with a fully independent 5G architecture utilising their own network core. Whilst in the Czech Republic the deployment of SA networks is still at the planning stage or in pilot projects[10] , in Germany

[10] For example, the operator T-Mobile has launched a pilot SA 5G network on the campus of the Czech Institute of Informatics, Robotics and Cybernetics (CIIRC) at the Czech Technical University in Prague. Similarly, SA 5G networks have been put into operation on other university campuses in Brno and Liberec. According to its
media reports, provides SA technology within private networks, for example in industrial sites (e.g. at Škoda Auto, see https://www.vodafone.cz/nejen-pro-media/press-releases/vodafone-launched-private-5g-network-at-skoda-/), it is still preparing for the transition to the new 5G network core on a wider scale, and the launch date for the 5G network in SA mode is not yet known (see media report from April 2024: https://www.lupa.cz/aktuality/cesky-vodafone-za-stovky-milionu-chysta-prechod-na-plnohodnotne-nove-jadro-mobilni-site-5g/).

5G networks in SA mode operate entirely as standard: the proportion of households with access to this 5G technology reaches up to 90 %). It is precisely in the availability of SA technology that the greatest difference in 5G network availability between the Czech Republic and Germany can be observed.

**Summary of the chapter and conclusion**

In Germany, 5G technology is available across 92% of the territory, with 5G connectivity available to 99.66% of households. It follows that in Germany there are virtually no so-called ‘white spots’, i.e. areas without access to 5G networks. More than 99% of households have access to 5G connectivity from more than one operator. Furthermore, Germany has a significantly higher proportion of standalone (SA) 5G networks, a technology that operates on its own independent 5G infrastructure. This technology covers 89.9% of Germany’s territory and is accessible to over 90% of households. The use of frequency bands is also an important factor. According to DESI data, the availability of 5G networks in higher frequency bands (3.4–3.8 GHz) in Germany is projected to reach 43.8% of households by 2023. Availability in lower frequency bands (700 MHz) therefore continues to predominate, as these are particularly suitable for covering less densely populated areas due to their greater coverage range.

The level of 5G network coverage in the Czech Republic and Germany is therefore roughly comparable, and in both countries the proportion of households with access to 5G networks is above the EU average. On closer inspection, however, it must be noted that the Czech Republic lags behind Germany in the development of 5G networks. Operators in Germany have already made significant investments in building a new, ‘proprietary’ 5G network core, which is reflected in the widespread availability of SA technology across the entire country. Operators in the Czech Republic, in the interest of a rapid launch of 5G connectivity, have relied on DSS technology, where the 5G network core is shared with the previous generation. Unlike their German counterparts, all operators in the Czech Republic therefore still need to make significant investments in the transition to SA technology.

Operators in Germany are currently focusing primarily on expanding the availability of 5G networks in the mid-frequency bands (3.4–3.8 GHz), particularly in urban areas where greater priority must be given to network capacity and other quality parameters. This also entails significant investment in densifying the base station network. By the end of 2023, connectivity in this band in Germany had reached over two-fifths of the population, and it is expected to continue growing. In this case too, operators in the Czech Republic are lagging behind – although they have held licences to operate 5G networks in the 3.4–3.8 GHz band since the start of 2021, significant investment in developing connectivity in this band have been made by only one operator, and the total proportion of the population with access to connectivity in the 3.4–3.6 GHz band is therefore only around 25%.

# 4 Summary of the availability analysis

## 4.1 Summary of the current situation compared with a selected EU country

In the Czech Republic, the development of 5G networks is at a level that is above average in the context of the EU as a whole and reaches figures similar to those in Germany. Whilst the proportion of the population with access to a 5G network varies between individual operators, almost 97% of the population is covered by at least one operator with access to 5G networks. In Germany, the availability of 5G network coverage is even higher, reaching almost 100% of households. From the population's perspective, therefore, there are virtually no 'white spots'; according to BNA data, these account for only a fraction of a percent of households. In the vast majority of cases (more than 99%), households have a choice of at least two operators.

In both the Czech Republic and Germany, different frequency bands are used for 5G. In the Czech Republic, the 700 MHz and 3.4–3.6 MHz bands were auctioned off. In addition to these new bands, individual operators also run 5G networks in the 1800 MHz and 2100 MHz bands, where they operate or have operated 3G and 4G technologies thanks to Dynamic Spectrum Sharing. In Germany, in addition to the 700 MHz and 3.4–3.8 GHz bands, the 26 GHz band (so-called millimetre waves, mmWave), which enables a significant increase in transmission speed and connectivity thanks to its bandwidth, albeit with significantly lower range and signal penetration; the networks are therefore suitable for connecting smaller areas with high-speed and high-capacity requirements (e.g. industrial sites, office buildings, etc.). In the Czech Republic, this band is not yet in widespread use; the use of millimetre waves is currently only being tested with the permission of the Czech Telecommunications Office (for example, in Prague's Chodov or Brumlovka districts[11] ) and it is not yet clear when this band will be made available to the general public.

However, there are significant differences in the use of these frequency bands. In Germany, 5G connectivity in the 3.4–3.8 GHz band is available to more than 43% of households, although this is still below the EU average. In the Czech Republic, by contrast, operators rely primarily on the 700 MHz band, which, whilst covering a larger area (and thus not requiring higher investment in a denser network of base stations), also offers lower capacity and speed. Although five operators have secured frequencies for providing 5G networks in this band, only O2, or rather its subsidiary CETIN, which owns the infrastructure, has so far invested significantly in developing 5G network coverage in this band. As a result, O2's 5G network in this band covers approximately one-fifth of the population. In the case of T-Mobile, this share is lower (though here too it is achieved primarily through infrastructure co-location with CETIN – as indicated by the fact that 5G network availability in this band is higher in the east of the Czech Republic than in the west) and reaches approximately 15% of the population. Vodafone, meanwhile, provides 5G connectivity in the blocks it acquired in the 3.4–3.6 GHz band to only a fraction of the population (approximately 1.3%).

There is also a significant difference in the availability of standalone (SA) technology. In Germany, this is completely dominant, with almost 90% of the population having access to the 5G network via SA technology. In the Czech Republic, the situation is the opposite; SA technology is currently used only in limited pilot operations (campuses, private networks in industrial enterprises) and investment in its widespread roll-out is only just being planned.

Both countries take a slightly different approach to calculating availability indicators. In Germany, 5G coverage is calculated at the level of 100 x 100 metre grid squares, and operators are responsible for measuring coverage, passing the data in this format to the regulatory authority. At the same time, minimum quality parameters are strictly defined to assess whether or not a 5G network is available in a given grid square. The data submitted by operators is verified by independent field measurements of signal quality and transmission speeds. In the case of the Czech Republic, independent measurements of 5G network coverage are currently only being carried out along railway corridors and motorways. Nationwide coverage is calculated based on a simulation that takes into account the deployment of base stations and terrain models.

Although the apparent availability of 5G networks in the Czech Republic and Germany is comparable, on closer inspection it must be noted that the Czech Republic lags significantly behind Germany. Operators in Germany have already made substantial investments in building a new, 'proprietary' 5G network core, which is reflected in the widespread availability of SA technology across the entire country. Operators in the Czech Republic have relied on DSS technology to ensure a rapid roll-out of 5G connectivity, whereby the 5G network core is integrated with the previous generation. High investment in the transition to SA

[11] https://www.lupa.cz/aktuality/rychlost-vzduchem-jako-na-optice-o2-v-praze-testuje-5g-milimetrove-vlny-na-26-ghz/

All operators in the Czech Republic, unlike their German counterparts, have yet to make this investment. Operators in Germany are currently focusing primarily on expanding the availability of 5G networks in the mid-frequency bands (3.4–3.8 GHz), particularly in urbanised areas where greater priority must be given to network capacity and other quality parameters. This also entails significant investment in densifying the base station network. Coverage in this band in Germany exceeded two-fifths of the population by the end of 2023 and is expected to continue growing. In this case too, operators in the Czech Republic are lagging behind – although they have held licences to operate 5G networks in the 3.4–3.6 GHz band since the start of 2021, significant investment in the development of connectivity in this band can only be observed with one operator, and the total proportion of the population with access to connectivity in the 3.4–3.6 GHz band thus stands at only around 25%. In the case of Vodafone, connectivity in this band is still in its infancy. In this case too, it must be noted that operators in Germany are significantly further ahead with the investments required for the development of 5G connectivity than is the case in the Czech Republic.

## 4.2 Current and anticipated barriers and limitations to expanding availability

As indicated above, the main constraint on the development of 5G networks in the Czech Republic is linked to the insufficient use of higher frequency bands and the need for investment in SA technology. To improve connection quality and capacity, it will be necessary to increase the proportion of standalone 5G networks and expand the use of the 3.4–3.6 GHz band. In other words, after obtaining licences to operate 5G networks, operators in the Czech Republic focused on rapidly expanding network coverage. In an EU context, the rate of population coverage by 5G networks in the Czech Republic is above average, and the scope for further growth is already very limited. In the coming period, however, investments in improving the quality of 5G networks are key, and in this area, operators in the Czech Republic are lagging behind other EU countries.

One of the main constraints on the expansion of 5G networks in the Czech Republic is the fact that most current 5G networks are operated as non-standalone (NSA). NSA networks utilise existing 4G infrastructure for certain key functions, which means that the true benefits of 5G, such as lower latency and higher capacity, are not fully utilised. Similarly, it is not possible to utilise other key benefits of 5G networks in NSA networks, such as Network Slicing technology, which enables providers to create virtual networks ('slices') for specific types of services or applications and to optimise them for those services – thereby making more efficient use of the network's potential and ensuring greater security, stability and resilience of key services[12] . SA networks are currently being developed in the Czech Republic only on a piecemeal basis, for example in the form of private mobile networks in industrial enterprises. A full transition to SA 5G technologies, which operate independently of 4G, is costly and requires extensive investment in new infrastructure. This transformation can be protracted and financially demanding, which slows down the overall development of 5G networks.

Another significant limitation is the low utilisation of mid-frequency bands, particularly the 3.4–3.6 GHz band. This band is key to providing higher speeds and capacity, which is essential for fully realising the potential of 5G technologies. Currently, most 5G networks in the Czech Republic operate in the 700 MHz band, which offers wide coverage but lower speeds and capacity. The development of mid-band connectivity involves further investment expenditure – it is necessary to increase the density of the base station network. However, another issue may also be the availability of suitable sites for base stations, particularly in urban areas (constraints may include not only limited space and regulations regarding the placement of stations on buildings, but also, for example, concerns among some members of the public – however unfounded – about increased electromagnetic radiation associated with a denser network of transmitters).

The scope for further increasing 5G network coverage is now rather limited. The 5G signal currently covers 96.8% of the population. This is still a slightly lower proportion than, for example, in Germany (where coverage exceeds 99% of households), though in the EU context it is an above-average figure. However, further expansion of coverage may now face disproportionately high investment costs when calculated per capita of the newly covered population. This is evidenced by the fulfilment of the so-called development criteria, which were linked to the auction of spectrum for 5G networks. As will be explained in more detail below, one of the conditions for the allocation of a block in the 700 MHz band (the block was awarded to the operator O2) was the obligation to cover at least 95% of the population in so-called 'white spots'. These white spots were defined as 212 municipalities in the Czech Republic which, at the time of the spectrum auction, were not sufficiently covered by broadband internet access; the condition for winning this block was to achieve 95% of the population covered by the signal in each of these municipalities within three years of the licence being granted (i.e. by February 2024) – except in situations where meeting the condition would require disproportionately high investment costs. By February 2024, however, the operator had met this condition in only 79 of the 212 designated municipalities. In the rest of the territory
In the "white spots" (i.e. in almost two-thirds of the remaining municipalities), the operator was granted an exemption on the grounds of disproportionately high investment costs required to meet the specified threshold. Consequently, in the remaining 133 municipalities, only 85% of the population was covered by a signal enabling connection to the 5G network. The process of renewing spectrum allocations for the 900 MHz and 1800 MHz bands, which was launched by the Czech Telecommunications Office (ČTÚ) in 2023, offers some potential for further increasing coverage in white spots; new development criteria have been formulated for the award of new allocations (the validity of the current allocations for two operators expires in October 2024) in both bands, new development criteria have been formulated, including improving the availability of 5G networks in under-served areas[13] .

---

[12] However, according to the CTO, there is as yet insufficient demand for this service.

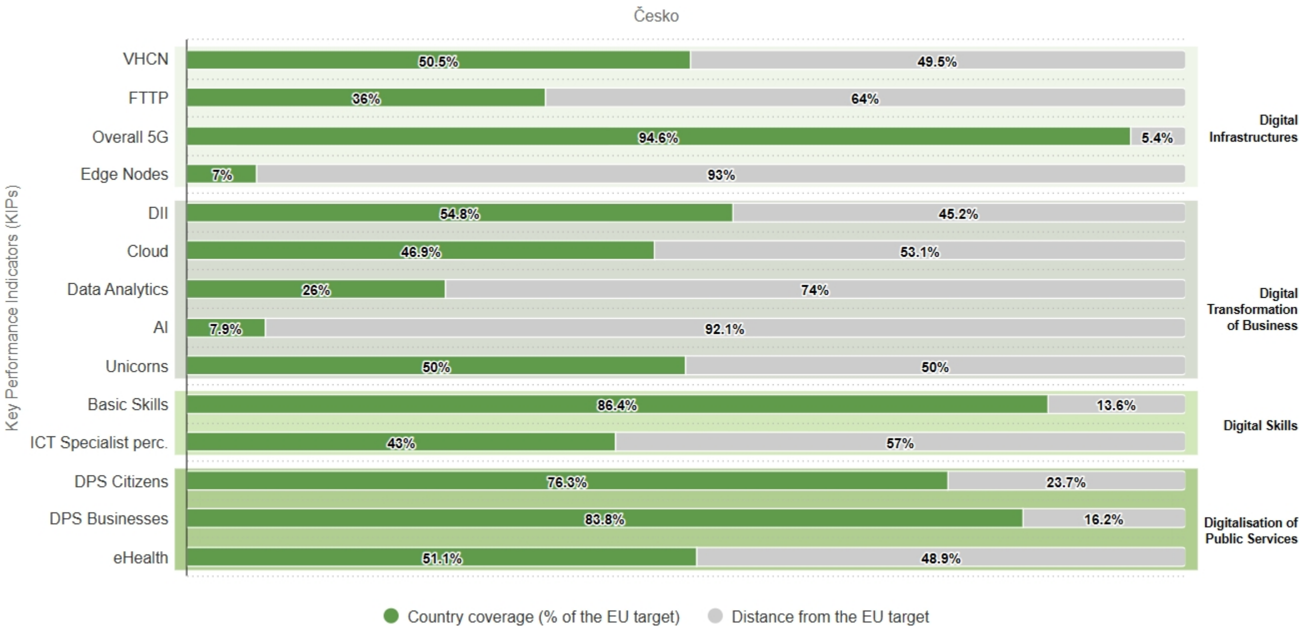
[13] For further details, see the Review Conclusions of 30 April 2024: https://ctu.gov.cz/sites/default/files/obsah/ctu/vyzva-k-uplatneni-pripominek-k-zameru-ceskeho-telekomunikacniho-uradu-udelit-pridely-radiovych/obrazky/20240430-Zavery_prezkoumani_900_a_1800_MHz.pdf

## 4.3 Expected future trend in the context of DESI

As mentioned in Chapter 1.3, the Czech Republic's position in the DESI indicator ranking is below average in the EU context. In the 2023 report, the Czech Republic ranked 19th out of 27 Member States in the overall assessment, despite the fact that the report also states that the rate of growth in the Czech Republic is higher than in a number of other EU Member States – and convergence is thus taking place, at least in part. According to the EC report, the main area in which the Czech Republic lags behind is the availability of digital infrastructure, which also includes the availability of 5G networks.

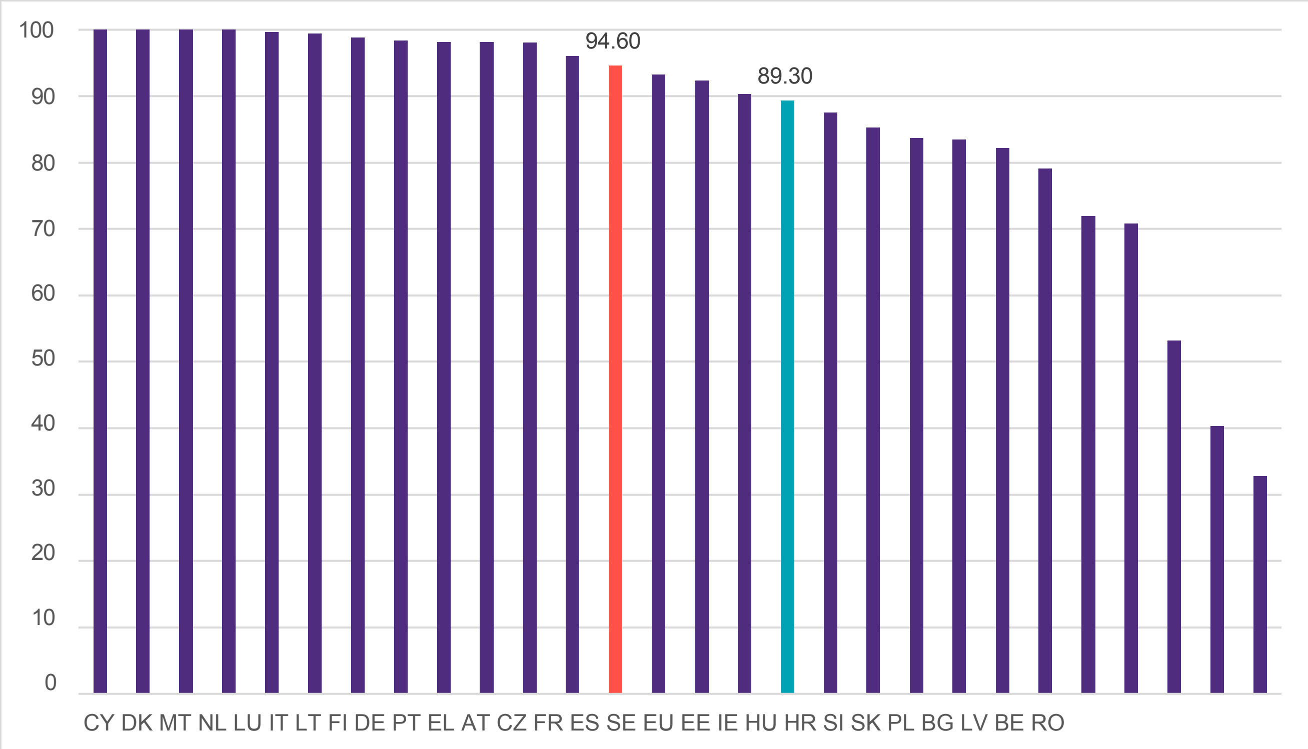
Yet the availability of 5G networks is the only area assessed within digital infrastructure where the Czech Republic achieves above-average scores compared to other EU countries. Conversely, however, when it comes to the availability of very high-speed internet (VHCN), the Czech Republic lags significantly behind other EU countries, and this trend is actually worsening.

*Figure 11: Current values of key DESI indicators in the Czech Republic compared to the set targets, DESI 2024 (data for 2023)*




*Source: DESI 2024*

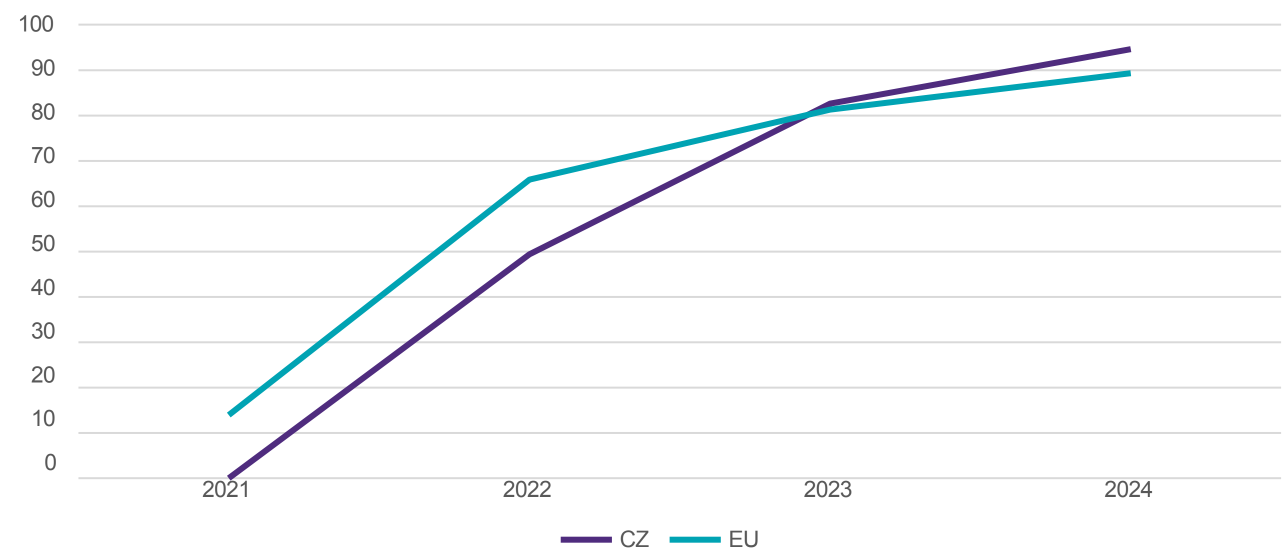
*Figure 12: Current values for 5G network availability – % of households covered, DESI 2024 (data for 2023)*




*Source: own analysis based on DESI 2024*

In 2023 (DESI 2024), the availability of 5G networks in the Czech Republic exceeded the EU average for the first time

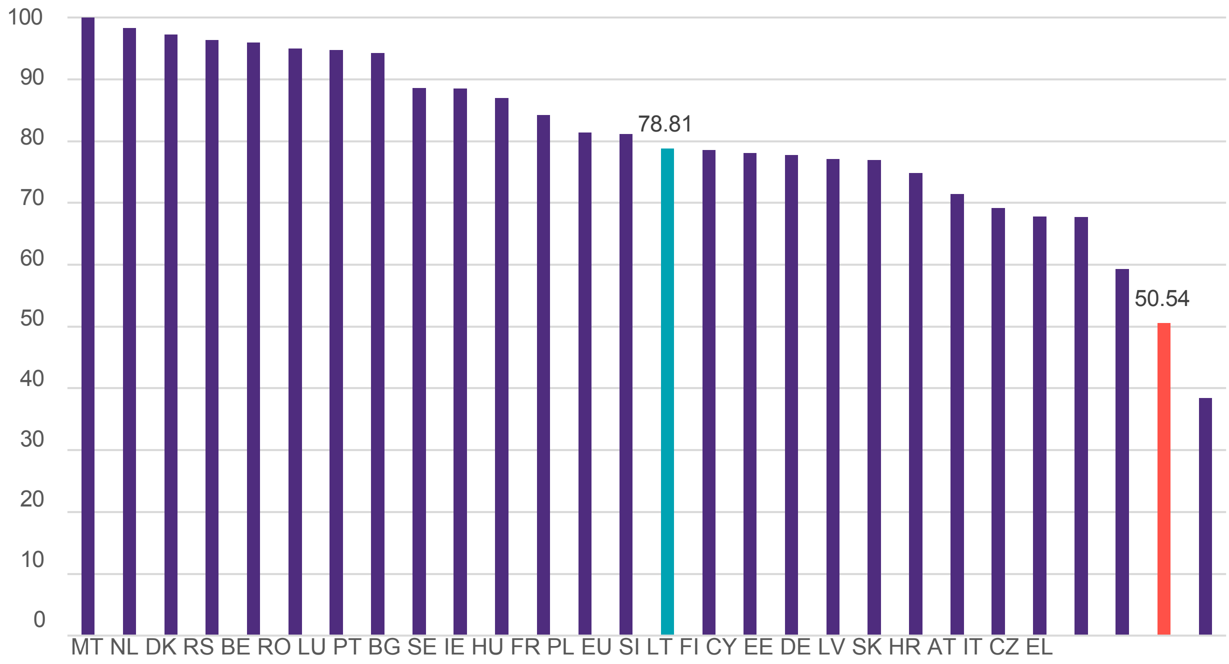
*Figure 13: Trend in 5G network availability – comparison of the Czech Republic and the EU (the years correspond to those of the DESI reports; the data therefore generally refer to the last day of the previous year)*




*Source: own analysis based on DESI 2024*

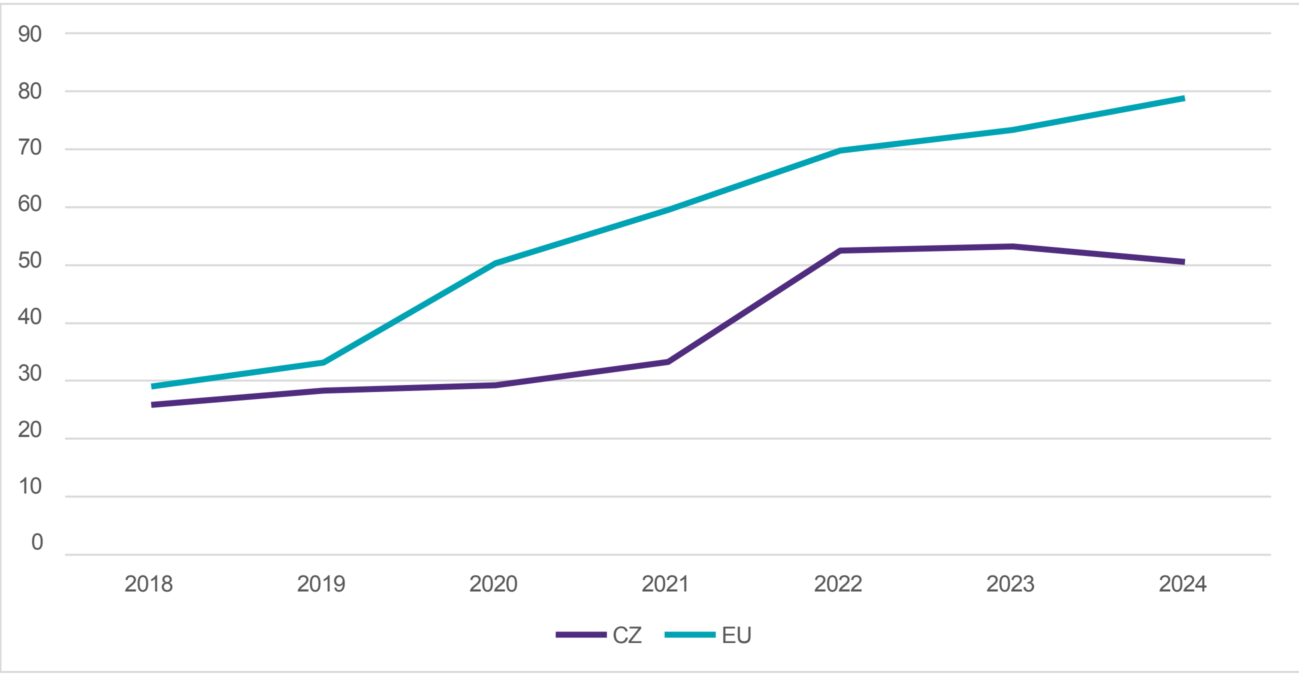
However, the situation is the opposite when it comes to access to VHCN: the Czech Republic’s figures are below average and the trend is not moving towards convergence

*Figure 14: Access to VHCN – % of households, DESI 2024 (data for 2023)*




*Source: own analysis based on DESI 2024*

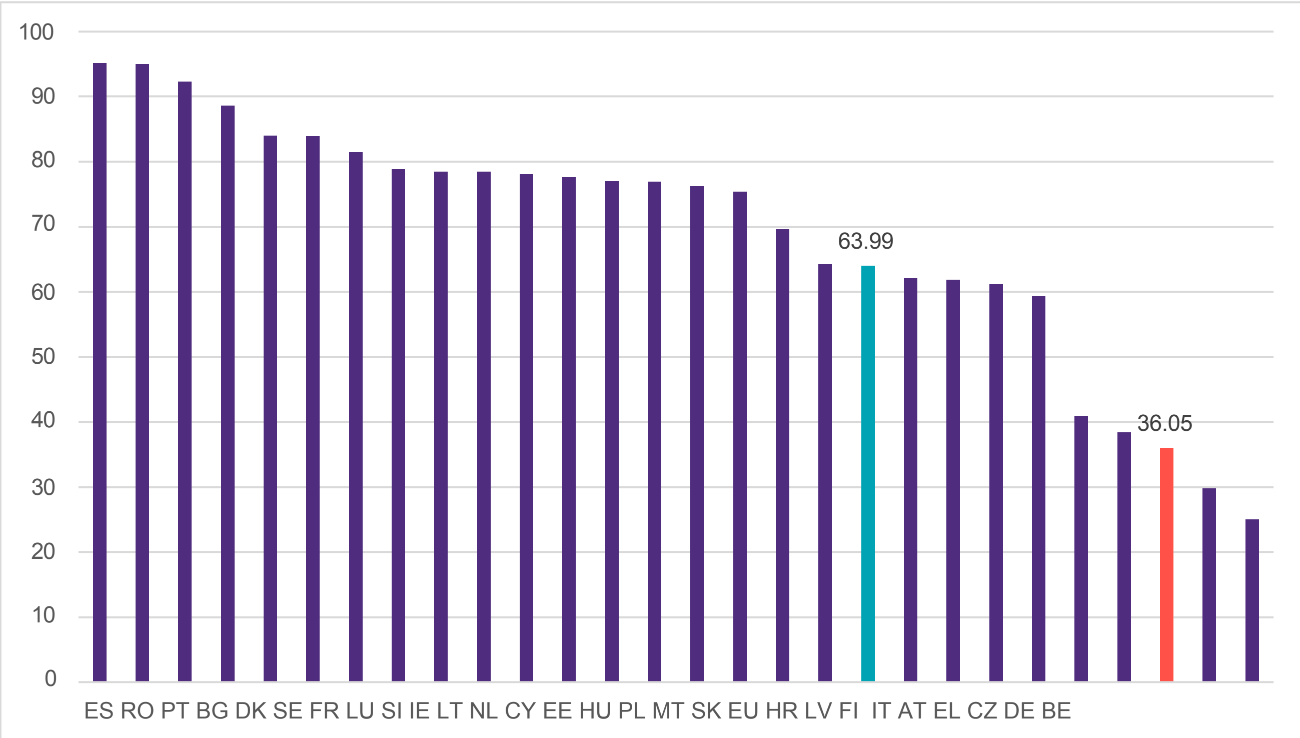
*Figure 15: Trend in VHCN availability – comparison of the Czech Republic and the EU (the years correspond to those of the DESI reports; the data therefore generally refer to the last day of the previous year)*




*Source: own analysis based on DESI 2024*

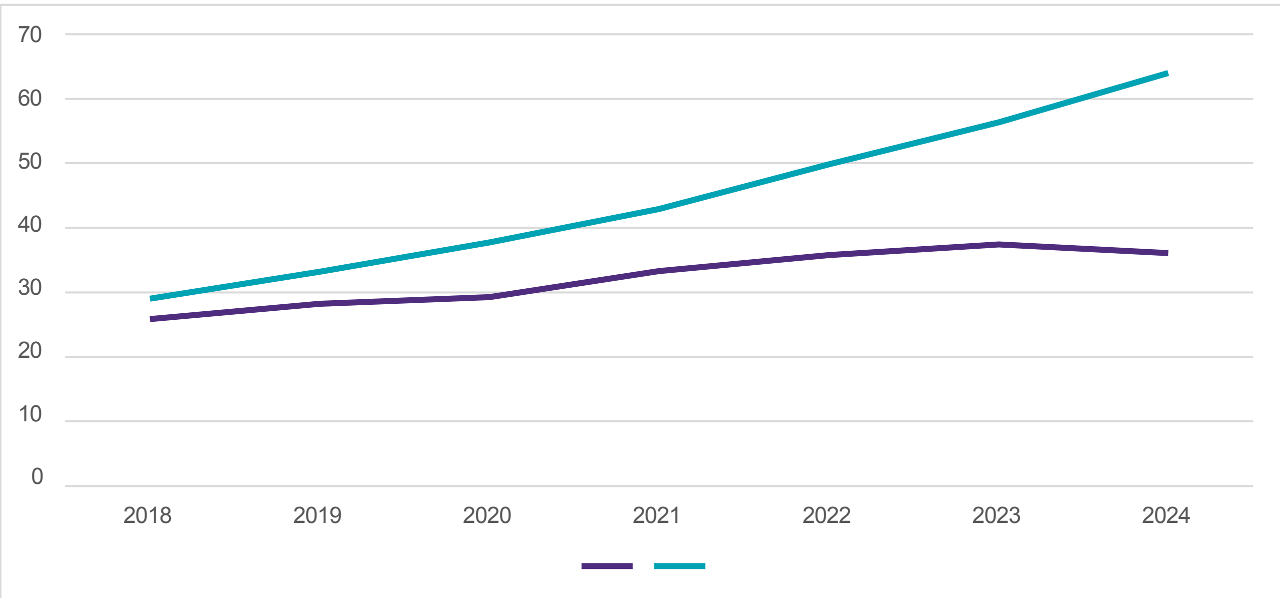
This lag of the Czech Republic behind the rest of the EU is primarily due to the low take-up of internet connections via fibre-optic networks (DOCSIS). The take-up of this technology in the Czech Republic is at a very low level compared to other EU countries and currently stands at only 36% of households (the third-worst figure).

*Figure 16: Current figures for fibre-optic network connectivity – % of households covered, DESI 2024 (data for 2023)*




*Source: own analysis based on DESI 2024*

*Figure 17: Trend in the availability of fibre-optic network connections – comparison of the Czech Republic and the EU (the years correspond to those of the DESI reports; the data therefore generally refer to the last day of the previous year)*




*Source: own compilation based on DESI 2024*

It is clear from the above that, in the area of digital infrastructure, the Czech Republic's main challenge lies in the trend towards gigabit connectivity, driven primarily by the indicator for the development of fibre-optic networks. Achieving the target of 95% coverage by 2030 would require a significant acceleration in the pace of deployment of these technologies and cannot be considered realistic. Taking into account the methodology used in the DESI calculation, the development of 5G networks in the Czech Republic has reached its upper limit – approaching 100%. The continued development of 5G networks cannot therefore offset the Czech Republic's lower ranking in the area of connectivity/digital infrastructure. On the contrary, it can be assumed that convergence will be observed in this indicator in the coming years, as this technology is gradually developed even in lagging EU Member States. The Czech Republic's relative position in the overall connectivity ranking is therefore likely to deteriorate. It cannot be assumed that, without substantial investment in infrastructure, there will be a significant increase in the proportion of households connected to very high-speed fixed internet in the foreseeable future – the Czech Republic will continue to lag behind on this indicator, whilst
the 'lead' that the Czech Republic currently holds in terms of 5G network coverage will diminish in comparison with other EU Member States. Assuming there is no change to the DESI methodology – i.e. the indicators included in this assessment – it is necessary to expect a trend of the Czech Republic's ranking deteriorating.

**Summary of the chapter and conclusion**

The key barriers and limitations to the development of 5G networks in the Czech Republic stem from the conclusions set out in the previous chapters. To improve connection quality and capacity, it will be necessary to increase the proportion of standalone 5G networks and expand the use of the 3.4–3.8 GHz band. In other words, after obtaining licences to operate 5G networks, operators in the Czech Republic focused on rapidly expanding network coverage. In an EU context, the rate of population coverage by 5G networks in the Czech Republic is above average, and the scope for further growth is already very limited. In the coming period, however, investments in improving the quality of 5G networks are key, and in this area, operators in the Czech Republic are lagging behind other EU countries.

The scope for further increasing 5G network coverage is now rather limited. The 5G signal currently covers 96.8% of the population. This is still a slightly lower proportion than in Germany, for example, but in the EU context it is an above-average figure. However, further expansion of coverage may already face disproportionately high investment costs when calculated per capita of the newly covered population.

In relation to the Czech Republic's ranking in the DESI index, the area of digital infrastructure and connectivity is assessed as below average compared to other EU countries and in relation to the stated goals of the 'Digital Decade'. However, this is not due to 5G network coverage – as mentioned, this is above average compared to other EU countries. The problem for the Czech Republic in light of the DESI assessment and the Digital Decade targets, however, is the trend in gigabit connectivity, caused primarily by the indicator
of fibre-optic network development. The Czech Republic's relative position in the overall connectivity assessment is therefore likely to deteriorate in the future. It cannot be assumed that, without substantial investment in infrastructure, there will be significant increase in the proportion of households connected to very high-speed fixed internet – the Czech Republic will continue to lag behind in this indicator, whilst the 'lead' that the Czech Republic currently holds in terms of 5G network coverage will
other EU Member States. Assuming there is no change to the DESI methodology, i.e. the indicators included in this assessment, it is reasonable to expect a trend of the Czech Republic's ranking deteriorating.

# 5 Analysis of qualitative parameters of 5G network availability in the Czech Republic

## 5.1 Data transmission speed and reliability

As mentioned in Section 2.2, the CTO has developed the so-called 'Methodology for the measurement and evaluation of data parameters of mobile electronic communications networks', which defines the methodology for measuring not only the availability of 5G networks but also qualitative parameters. This measurement is carried out using two methods: stationary and in-vehicle. However, no publicly available data from stationary measurements is currently available that could provide input for the evaluation of quality parameters, particularly connection speeds. Data from in-vehicle measurements are available, as the assessment of coverage availability on defined corridors is one of the so-called development criteria – the allocation of frequencies was subject to the condition of achieving 100% coverage of main corridors and 98% of secondary corridors within four years of the date this decision takes legal effect (i.e. by early February 2025).

Measurements of quality parameters on the corridors therefore provide robust data for assessment – they are carried out in accordance with the CTO's binding methodology. At the same time, however, they cover too small a proportion of the Czech Republic's territory to be relevant to the current situation in the Czech Republic as a whole. For this reason, the analysis of quality parameters is supplemented by other sources:

- Ad-hoc measurements carried out by third parties;
- Measurement results from users of the NetTest mobile app. This is a tool operated by the CTO that provides users with information on the quality of their internet access service in the form of actual download, upload and ping speeds. This data from individual measurements, including accompanying information on internet connection technology, geographical location, signal strength (in the case of mobile data), etc., is stored on the CTU server and is also available as open data – it is therefore possible to use it for at least a partial evaluation of the quality parameters of 5G networks[14] . Unlike many commercial connection testers, the NetTest tool therefore carries out measurements using the ČTÚ's certified methodology, whilst also providing sufficient data points (individual measurements) for evaluation.

### 5.1.1 Ad-hoc measurements and media coverage

The operator O2 places particular emphasis on the qualitative parameters of 5G connections in its media coverage. To this end, it collaborates with the Czech Institute of Informatics, Robotics and Cybernetics at the Czech Technical University in Prague, which carries out measurements of network qualitative parameters using its certified F-Tester technology[15] . At the same time, however, it is important to bear in mind that the client commissioning this commercial testing is one of the operators providing 5G connectivity – detailed results of this measurement are therefore not available; information is provided only in media releases from the operator or representatives of CTU.

The aforementioned measurements were carried out by CTU twice, namely in spring 2022 and autumn 2023. Both measurements showed that O2 provides the highest 5G connection speeds, with the average measured download speed according to CTU's measurements reaching approximately 281 Mb/s (measurement from autumn 2023), which significantly exceeds the average speeds achieved by other operators (157 and 118 Mbps respectively). The figures are slightly higher than in the spring 2022 measurements, when average speeds reached 217 Mbps for O2 and 117 and 87 Mbps respectively for the other two operators. The connection provided by O2 also achieved significantly better results in other measurement parameters, particularly in terms of response speed.

[14] For more details on the tool, see https://nettest.ctu.gov.cz/cs/

[15] See https://f-tester.fel.cvut.cz/.

However, it must be emphasised once again that the measurement was commissioned by this operator. According to representatives of the Czech Technical University (ČVUT), the significant difference in speed compared to competitors is primarily due to the fact that O2 was the first operator to launch a 5G network in the 3.7 GHz frequency band and has the widest coverage in this frequency band of all operators (covering more than 20% of the population in this band). Thanks to the sufficient channel bandwidth available to operators in these bands, higher speeds can be achieved. It can therefore be assumed that the measurements were carried out primarily in areas where O2 (or its sister company CEITIN), unlike other operators, has 5G connectivity available in this higher frequency band.

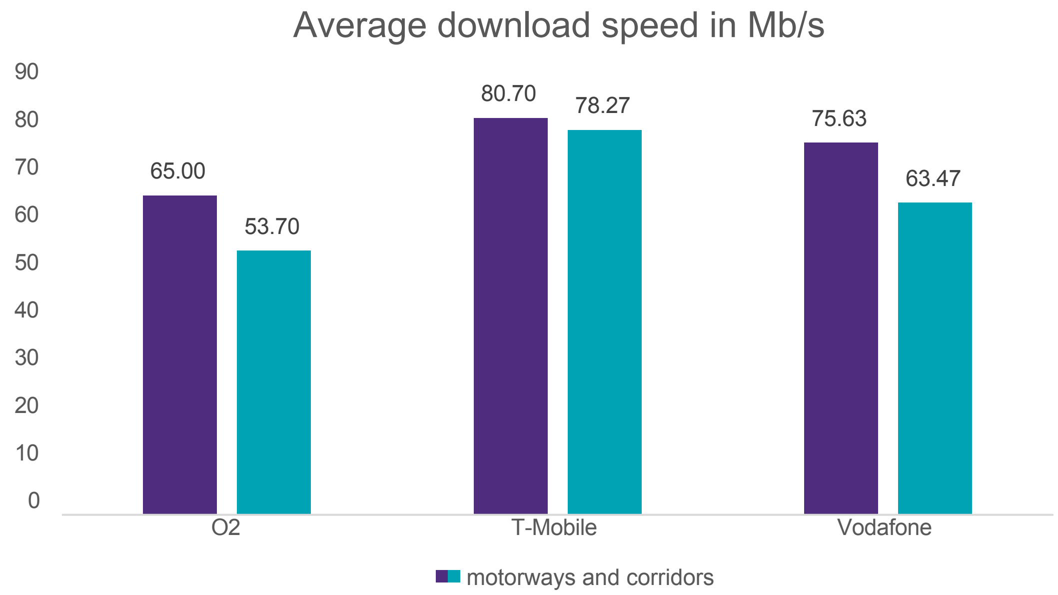
The operator O2 also states in its media communications that its customers perceive its 5G network connection as the fastest – but it must again be emphasised that this is based on a questionnaire survey commissioned by O2 itself.

### 5.1.2 Data from motorway and corridor measurements

The data produced by the CTO in accordance with the above-mentioned methodology during so-called drive-by measurements provide a different picture of the quality parameters of 5G networks than is the case with ad-hoc measurements and media reports. Measurements on motorways were carried out in two periods, namely from 29 November to 18 December 2023 and from 3 to 17 January 2024. In total, nearly 230,000 data points from these measurements are available. Measurements on the corridors took place between 6–14 November 2023, 29 January to
1 February 2024 and 26–28 February 2024, with a total of almost 415,000 records available. Measurements were always carried out simultaneously for all three operators.

The results clearly show that O2, on the other hand, achieves the lowest average internet connection speeds in both types of measurement. See the following graph:

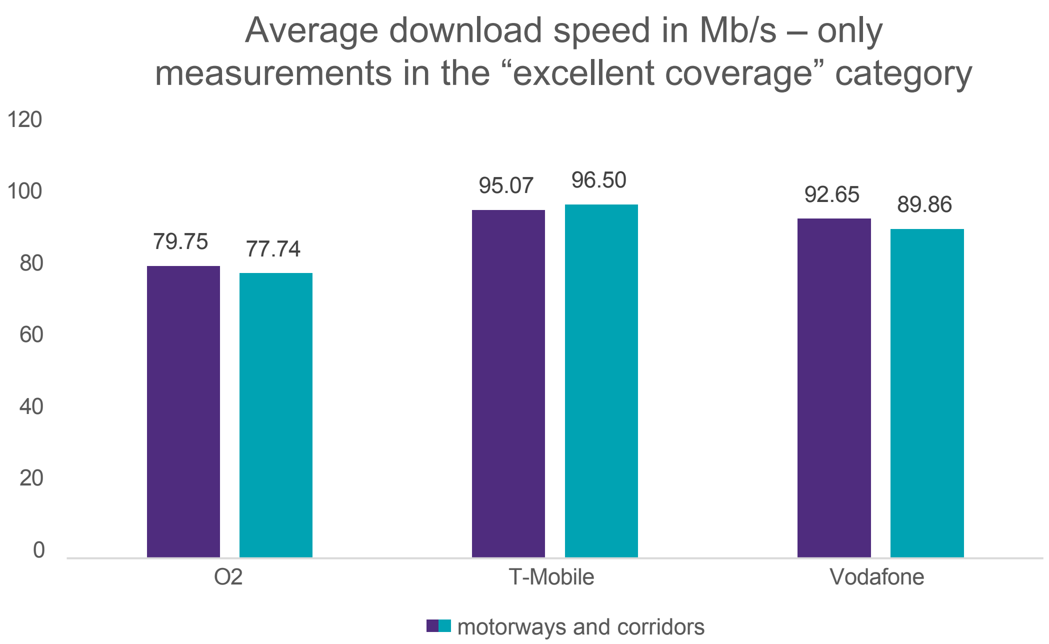
*Chart 7 Comparison of average download speeds on individual operators' 5G networks according to ČTÚ measurements*




*Source: own analysis based on CTU data*

This difference is partly due to poorer 5G network coverage in the case of the operator O2. However, it does not fully explain these differences. Whilst it is clear that in the highest connection quality category (measured on a scale of 1 – no coverage to 5 – excellent coverage), O2 achieves a connection rating of 5 in 77% of measurements on motorways and 62% on corridors, whilst the other two operators show slightly higher proportions of measurements in the highest category (82% and 78% for T-Mobile and 78% and 65% respectively for Vodafone) and, at the same time, the highest proportion of measurements in the 'no coverage' category – more than 5% for corridors. However, if we were to consider only measurements from the highest category, i.e. 'excellent' coverage, the ranking of operators and the differences between the connection speeds achieved would not change significantly:

*Chart 8 Comparison of average download speeds on individual operators' 5G networks according to CTU measurements – only measurements in the 'excellent coverage' category*




*Source: own analysis based on CTU data*

## 5.1.3 NetTest app measurement results

As mentioned, the data from the NetTest app measurements is generated by the users themselves, so it must be interpreted with this limitation in mind. It is not a representative sample measuring connection quality, but rather randomly generated data in terms of both geography and time. Nevertheless, given a sufficiently large sample size, it may still be informative.

The data was extracted from the CTU system for the period January 2023 – June 2024. Only data where a 5G connection was measured with one of the three mobile operators was filtered. Data generated outside the Czech Republic, i.e. whilst roaming, was removed from the sample. Consequently, 21,044 records of individual 5G connection speed measurements were included in the analysis. To minimise distortion caused by weak signals, only those measurements where the signal strength, as measured by the RSRP (Reference Signal Receive Power) variable, reached at least -90 dBm or higher were included in the sample. The sample was thus reduced to 4,388 records.

The values of the key quality parameters from these measurements are shown in the following table:

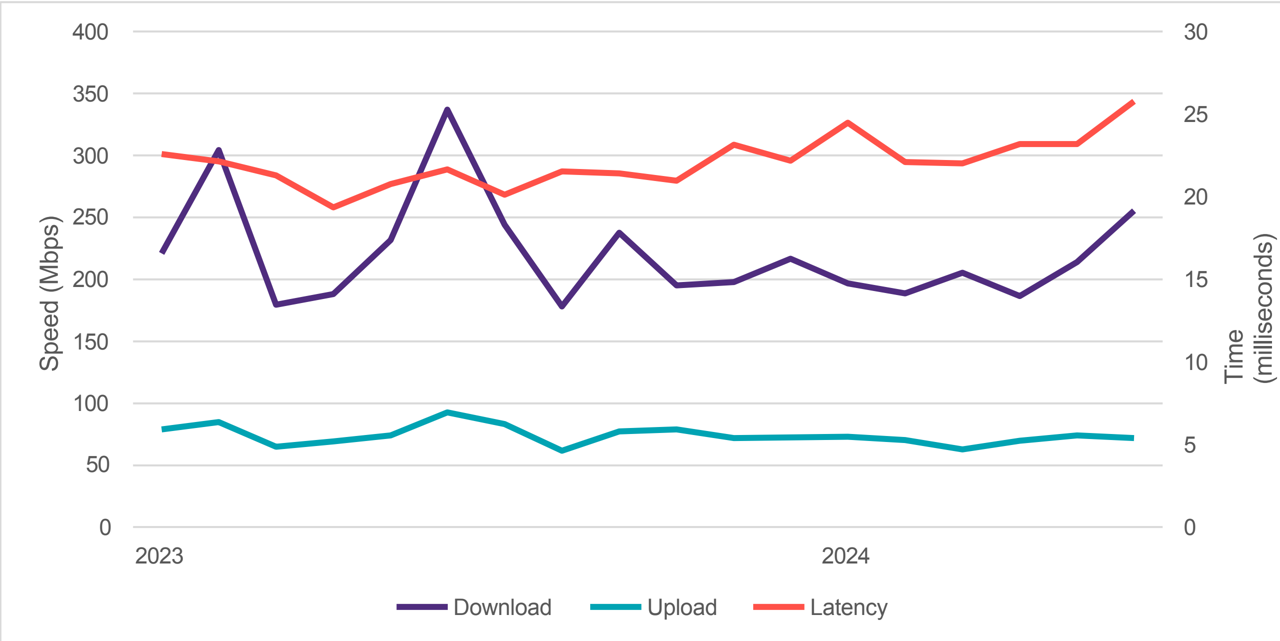
*Table 3 Values of 5G connection quality parameters in the Czech Republic according to NetTest data, January 2023 – June 2024*

| | **Average 1/2023 – 6/2024** | **Median 1/2023 – 6/2024** |
|---|---|---|
| Download speed | 218.66 Mb/s | 161.81 Mb/s |
| Upload speed | 73.38 Mbps | 75.92 Mbps |
| Latency (response time) | 22.15 ms | 20.04 ms |

*Source: Own analysis based on CTU data*

Over time, a fairly constant trend can be observed; the average values for individual months do not differ significantly. However, this may be due to the fact that when disaggregated along the time axis (for example, by month), the total number of measurements is already relatively low (in the hundreds).

*Figure 9 Development of quality parameters over time according to NetTest data*




*Source: Own analysis based on data from the Czech Telecommunications Office*

However, significant differences can be observed between individual operators which, with the exception of average upload speed, correspond to the claims made by O2, albeit with smaller differences between operators than those stated.

*Table 4 Differences between operators on key quality parameters according to NetTest data for the period 1/23 – 6/24; average / median*

| | **Download (Mb/s)** | **Upload (Mb/s)** | **Latency (ms)** |
|---|---|---|---|
| *O2* | 296.13 / 224.34 | 72.69 / 64.97 | 19.12 / 19.00 |
| *T-Mobile* | 232.35 / 191.31 | 89.86 / 95.24 | 22.82 / 20.21 |
| *Vodafone* | 122.75 / 97.60 | 59.09 / 50.96 | 24.80 / 20.85 |

*Source: Own analysis based on data from the Czech Telecommunications Office*

# 5.2 Differences between urban and rural areas

The difference in 5G network coverage between urban and rural areas was already discussed in Chapter 2.3. According to the DESI indicator definition, rural areas are defined as territories with a population density of less than 100 people per $km^2$ . Under this definition, and when applying the criterion at the municipal level, 73% of the Czech Republic's territory (excluding military training areas) is classified as rural, home to approximately 22% of the population. Detailed coverage data by region category are presented in the following table:

*Table 5 Availability of 5G network connectivity by operator*

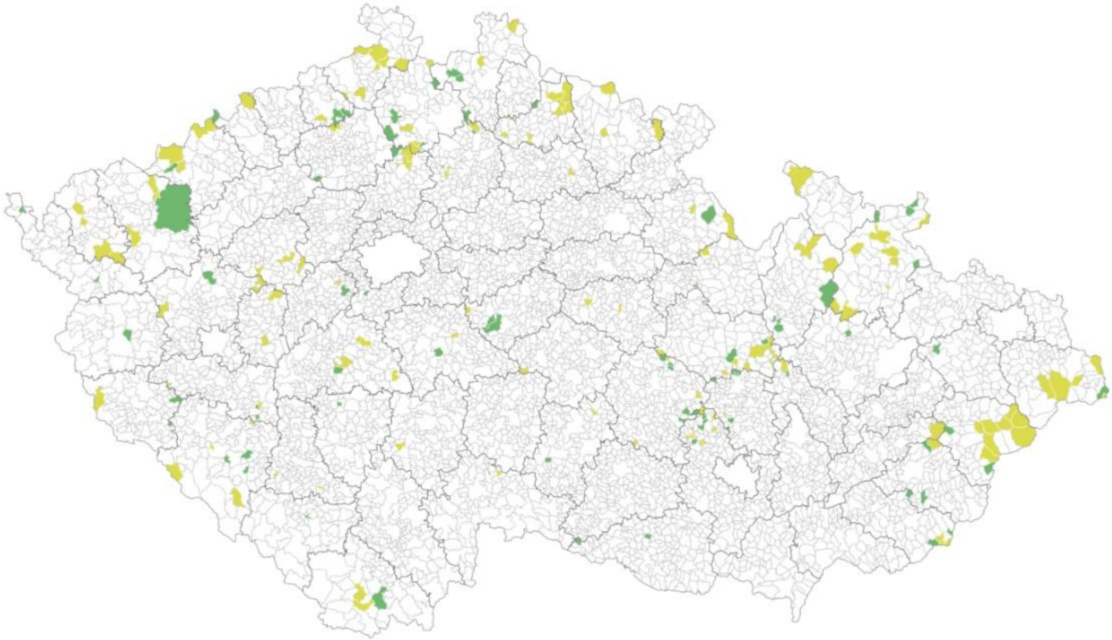
| | | **Availability of 5G connectivity** | | | |
|---|---|---|---|---|---|
| | Population | O2 | T-MOBILE | VODAFONE | At least 1 operator |
| **Rural areas** | 2,318,211 | 57.3% | 64.2% | 74.5% | 87.3% |
| **Urban areas** | 8,205,956 | 91.7% | 95.4% | 97.1% | 99.1% |

*Source: Own analysis based on CTU data*

So-called 'white spots' play a significant role in connectivity. One of the conditions of the auction for frequencies in the 700 MHz band in Block A3 is the obligation to cover at least 95% of the population in these white spots within three years of the decision on the allocation of frequencies becoming legally binding. However, this obligation does not apply to those white spots where coverage could only be achieved at the cost of disproportionately high investment costs. Block A3 was won by the operator O2, and given that the decision came into force in February 2021, the deadline for fulfilling this obligation was 4 February 2024.

The auction conditions identified a total of 212 municipalities as such 'white spots' to which the condition applies. As of 4 February 2024, the condition of covering at least 95% of the population had been met in only 79 municipalities (of which, in one municipality, the condition was met because no one currently lives there), where 98% of the population was covered by 5G networks. However, for the majority of municipalities (133, i.e. 63%) designated as white spots, the operator was granted an exemption on the grounds of disproportionately high costs, and the condition therefore did not have to be met. A total of 57,317 people live in these municipalities where the condition of disproportionately high costs was recognised, and 48,801 people, or approximately 85%, have access to a 5G network (the median is almost identical). Less than 50% of the population is covered by the 5G network in only 12 municipalities designated as 'white spots' (in which a total of 2,172 people live). In total, 82,611 people live in these white spots, and 73,600 of them, or 89%, have access to the O2 operator's 5G network (to which this condition applies).

*Figure 18 White spots and their coverage*



*Source: ČTÚ; Legend: municipalities falling within white spots where the obligation has been fulfilled are coloured green; municipalities where the costs of fulfilling the condition were deemed unreasonably high are coloured yellow.*

The significance of this condition regarding coverage of white spots is evidenced by the fact that the other two operators, which achieve significantly higher coverage of both people and territory across the Czech Republic as a whole than O2, achieve significantly lower coverage figures in the municipalities defined in this way: In these municipalities, Vodafone provides 5G internet connectivity to a total of 45,656 people, or 55.3% of the population, whilst T-Mobile provides it to just 32,444 people, or 39.3%. It is therefore clear that the condition in the auction served its purpose – as the data from the other two operators show, coverage of these white spots cannot be achieved on a purely commercial basis.

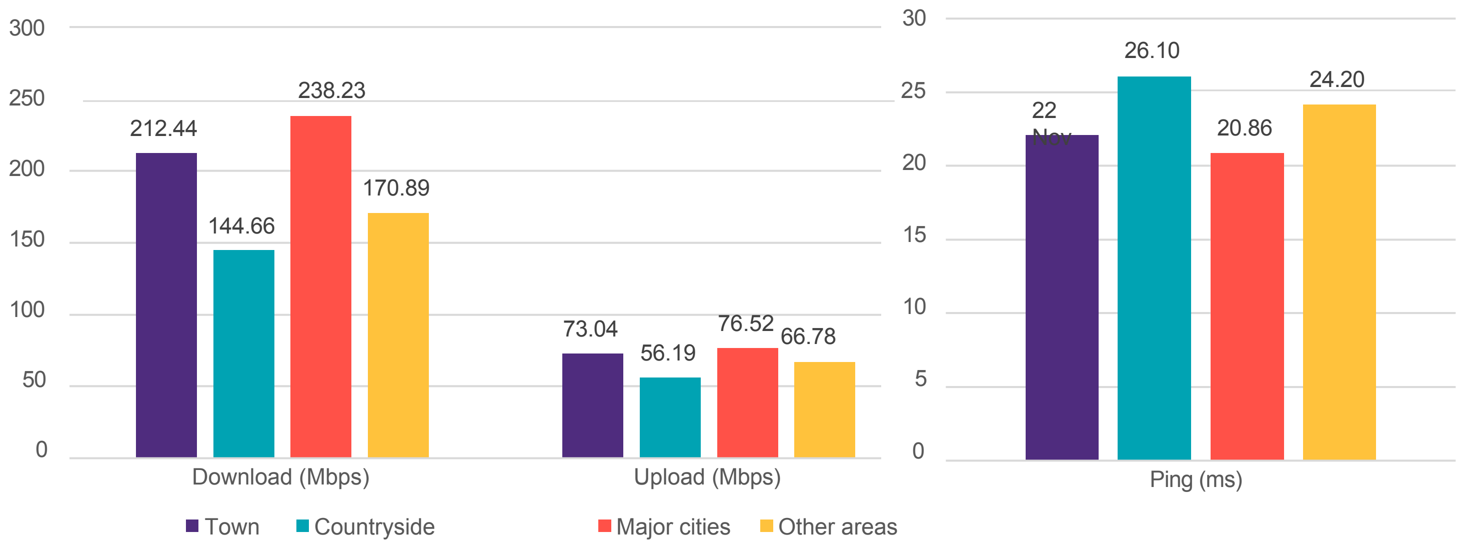
There is insufficient data to conduct a robust analysis of the differences in connection speeds between urban and rural areas. As mentioned above, stationary measurements of 5G network availability and its quality parameters have not yet been carried out, or rather, the data from these measurements have not been published. Data from drive-by measurements are therefore very difficult to use for defining differences between rural and urban areas – primarily because the routes of these corridors / motorways mostly run outside built-up areas; assigning individual points to urban or rural areas (solely on the basis of the point's location within the cadastral territory of the municipality through which the line of infrastructure passes at the time of measurement) would therefore be highly misleading.

Consequently, to indicate differences in the quality parameters of 5G network connections, only open data from measurements in the NetTest application can be used, at least in part. This is because the metadata from the measurements also records the geographical location of the device on which the measurement is run. At the same time, however, it is necessary to point out once again that **the results of this analysis cannot be regarded as firm conclusions; rather, they merely indicate a trend**. Apart from the limitations associated with the use of data mentioned above (arbitrary data points – data are generated ad hoc by individuals who run the CTU NetTest application on their devices; regional distribution is therefore also significantly uneven), the concentration of data points in urban areas is also a significant limitation. According to the definition of rural areas presented above (population density of less than 100 inhabitants per $^{km^2}$), only 3.6% of all measurements were carried out in rural areas (even though 22% of the population lives in these areas). To increase the validity of the analysis, we therefore carried out a further classification, comparing measurement results in large cities (10 regional capitals with approximately 90,000 or more inhabitants – i.e.

all regional capitals except Karlovy Vary, Jihlava and Zlín) with the rest of the Czech Republic. With this division, the sample was split in a ratio of approximately 58:42 (in favour of large cities), so the results of the analysis are more robust[16] .

The results of these assessments, expressed as average download and upload speeds and average latency, are shown in the following graphs.

*Figure 19 Comparison of 5G network quality parameters based on measurements using the NetTest tool*




*Source: own analysis based on NetTest data*

The data presented above, despite the limitations in their interpretation outlined above, suggest that there is a significant difference in all quality parameters when comparing urban and rural areas. As already mentioned, the results are partially skewed due to the high number of measurements taken in the capital city of Prague. However, even if we were to carry out the analysis excluding data for the capital city of Prague, a significant difference in quality parameters would remain. In such a case, download speeds would differ by approximately 35 Mb/s (180 Mb/s in urban areas), upload speeds in urban areas would decrease to 66.8 Mbps (still a difference of more than 10 Mbps compared to rural areas), and latency in urban areas would, conversely, increase to an average of nearly 24 ms (still more than 2 ms lower). However, it must be reiterated that this data must be interpreted with caution, bearing in mind the rather indicative nature of the analysis's conclusions – due to the limitations in both the quality and quantity of the input data discussed above.

At the same time, however, it must also be noted that the qualitative parameters are not directly proportional to the population density and/or the number of inhabitants of a given locality. The correlation between these variables (i.e. the results of measurements of individual parameters on the one hand and the population density or number of inhabitants of a given settlement on the other) reaches a maximum value of approximately 0.22 – a value that is still too low to classify these variables as mutually dependent (moreover, if we were to remove data for the capital city of Prague from the sample, the correlation values would be almost zero). This fact can also be illustrated by dividing the sample into quartiles (see the matrix below) – it is not even visually apparent in the matrix that the records 'cluster' along its diagonal; it cannot therefore be inferred that there is a direct proportional relationship between these variables. The significantly higher number of records in the fourth quartile in terms of both population growth rate and density (i.e. the number of measurements in the top 25% of values recorded in the quarter of settlements with the highest population density) can again be explained by the high number of measurements in the City of Prague[17] .

[16] At the same time, it must be emphasised that more than a third of the measurements (36%) were taken in the capital city of Prague – this fact naturally also distorts the results.

[17] The fourth quartile contains only measurements from the capital city of Prague – it is therefore skewed and includes significantly more records than a true quartile; a proportionally lower number of records is then contained in the third 'quartile' according to population density

*Table 6 Matrix of population density and download speed distribution in 5G networks by quartiles*

| Population density (persons/km²), number of records | Download speed (Mb/s) – number of records: I | II | III | IV |
|---|---|---|---|---|
| **I (0–25%)** | 235 | 300 | 307 | 171 |
| **II (25–50%)** | 365 | 280 | 264 | 245 |
| **III (50–75%)** | 91 | 106 | 106 | 70 |
| **IV (75–100%)** | 303 | 307 | 318 | 509 |

*Source: Own analysis based on NetTest data*

According to the analysis of NetTest data, the quality parameters of 5G network connections therefore differ by an average of approximately 30–50% between urban and rural areas. At the same time, however, there is no clear direct correlation – it cannot therefore be claimed that quality parameters decrease in direct proportion to the population density or the number of inhabitants in a given municipality. At the same time, however, it is necessary to reiterate that these analysis results are merely indicative; for a more robust analysis, a significantly higher number of measurements from rural areas and a more balanced regional distribution of measurements would be required.

## 5.3 Availability in high-load situations

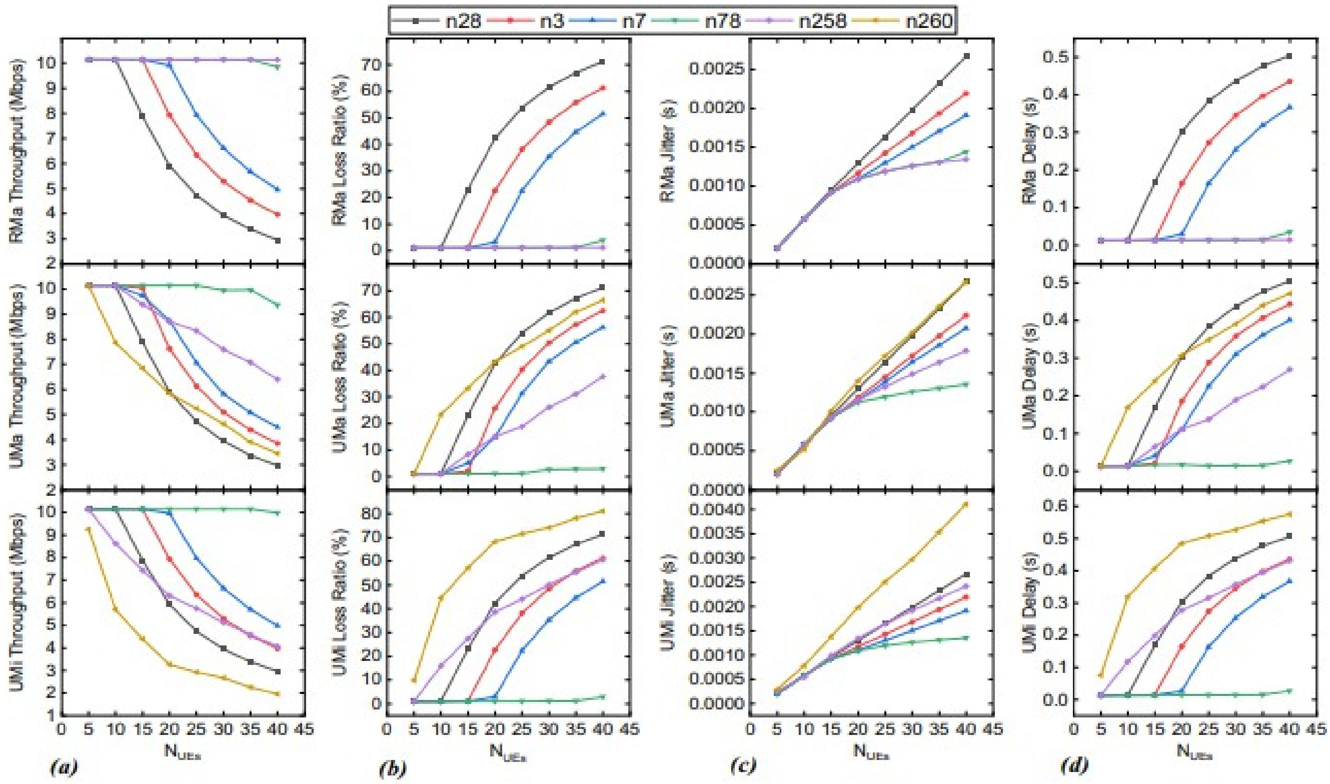
The resilience of 5G networks to high-load situations is influenced by a number of factors. One of the key factors is, among other things, the frequency band in which the 5G connection is provided. In this context, a significant role is also played by whether the technology is
'standalone' (SA) technology, which features a fully independent 5G architecture using its own network core, or whether the connection is provided as 'non-standalone', where the network uses the existing 4G (LTE) architecture as the basis for signal and connection management – this can be a weak link in high-load situations[18] . Other factors include, for example, the physical characteristics of the area in question (particularly whether it is built-up or open), distance from the transmitter, etc.[19] .

In general, therefore, the availability and quality of connection to 5G networks depends on the number of connected devices in a given cell. Due to network capacity limitations, as the number of users increases beyond a certain threshold, the network becomes overloaded and the quality of services provided deteriorates. See, for example, the detailed quantitative analysis (model) below:

[18] See, for example, GSMA (2019): *The 5G Guide: A Reference for Operators*; similarly, see also, for example, Nybsys: *What is 5G Standalone: Is it Different from 5G Non-Standalone* or Spirent (2024): *5G 2024: Market Drivers, Insights & Considerations.*

[19] For a detailed discussion of the factors influencing the quality parameters of 5G networks and their modelling, see, for example, Malekzadeh, M. (2023): *Performance prediction and enhancement of 5G networks based on linear regression machine learning*, EURASIP Journal on Wireless Communications and Networking; or He, A. (2016): *Performance Evaluation and Enhancement in 5G Networks: A Stochastic Geometry Approach*; similarly, see also Lorincz, J et al. (2020): *Analyses of User Density Impact on Energy-efficiency Metrics in 5G Networks*.

*Figure 20 The effect of user density on network performance parameters in terms of throughput, loss ratio, connection delay and packet jitter in three scenarios – 'Rural Macrocell' (RMa), "Urban Macrocell" (UMa) – i.e. mobile signal in an outdoor environment – and "Urban Microcell" (UMi); the relevant bands are n28 (700 MHz) and n78 (3.5 GHz). Units are specified in each graph.*




*Source: Malekzadeh 2023: 17*

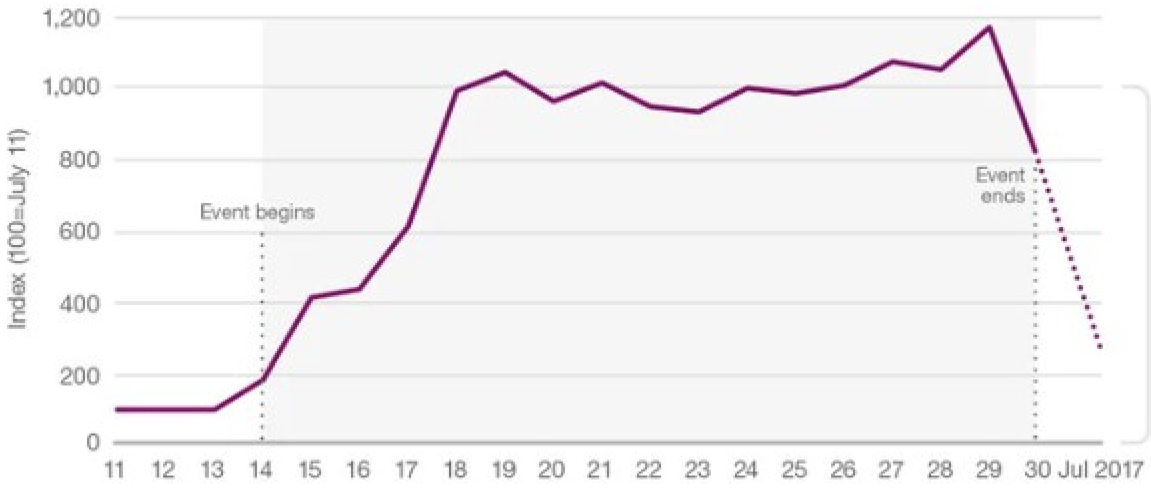
However, both sources and user experience agree that, with the exception of non-standard situations such as cultural or sporting events, festivals, etc., instances of network congestion are significantly less common compared to older technologies. For example, a 2021 analysis by Opensignal[20] states that no instances of network congestion were recorded, even in markets with high 5G adoption. (This conclusion is supported, among other things, by the fact that data transmission and user experience are significantly more consistent throughout the day than with older, previous technologies[21] ).

However, in situations involving high concentrations of people, measures must be implemented to enhance the availability and coverage of 5G networks. As noted in Ericsson's analysis, with the ongoing expansion of 5G networks and the associated increase in the availability of high-quality mobile internet connectivity, changes can be observed in the behaviour of visitors to mass events, which significantly increase demands on data transmission – for example, visitors stream videos from the event, communicate on social media, etc. However, significantly higher demands on data traffic are also driven by supporting infrastructure (such as established cashless payment systems) and services for visitors. These increased demands are illustrated by the experience of organising a sporting event in Hungary in 2017, during which there was a more than tenfold increase in data traffic:

[20] Rizzato, F. – Fogg, I. (2021): *Quantifying the Impact of 5G and Covid-19 on Mobile Data Consumption.*

[21] See https://www.opensignal.com/2023/06/29/5g-is-more-consistent-than-4g-across-all-hours-of-the-day-in-the-uk

*Figure 21 Daily increase in mobile data traffic during a sporting event in Hungary in 2017*




*Source: Ericsson 2017*

*Legend: data is presented as an index, where 100 = the value for 11 July. The grey section of the graph marks the duration of the event from start (event begins) to finish (event ends).*

This experience is confirmed by operators. For example, the British operator Vodafone reports that during the five-day Glastonbury music festival in 2023, 169 TB of data was transferred via its network, which is more than double the volume from the previous year (https://www.ccsinsight.com/blog/uk-operators-dial-up-coverage-at-major-events/). A comparison of data traffic volumes for other events held in the UK in 2023 is shown in the following table:

*Table 7: Data volumes transmitted on the Vodafone network at selected events in 2023*

| Event | Number of participants (estimate) | Number of mobile base stations used (Cells on Wheels) – Vodafone | Data volume transferred during the event (GB) |
|---|---|---|---|
| **Glastonbury** | 200,000 | 9 | 168,754 |
| **Badminton Horse Trials** | 200,000 | 2 | 9,524 |
| **Wimbledon** | 532,000 | 1 | 64,159 |
| **Royal Ascot** | 266,000 | 2 | 21,373 |

*Source: https://the-mobile-network.com/2023/09/special-events-can-be-a-special-headache-for-mobile-operators/*

The domestic operator T-Mobile then reports that during the three-day Colours of Ostrava festival, which typically attracts 30–40,000 attendees, it transmitted approximately 18 TB of data in 2023 – partly because, as the festival's general partner, it provided a cashless payment system and other services for visitors (see https://smartmania.cz/t-mobile-je-novym-generalnim-partnerem-colours-of-ostrava/).

To address these demands on the availability and quality of 5G networks in situations with (anticipated) high load, the following solutions are primarily used:

- **Infrastructure reinforcement.**
    - Particularly in indoor areas where a high concentration of people can be expected, small cells and antennas are installed that operate primarily in higher frequency bands and are thus capable of providing higher data transmission capacity (with a shorter range, which is not a key factor when installed indoors). For example, the operator O2, or rather its sister company – the infrastructure owner CEITIN – significantly upgraded the infrastructure at the O2 Arena in Prague ahead of the 2024 Ice Hockey World Championship to provide internet connectivity via LTE and 5G technologies, primarily in higher frequency bands.[22] Thanks to this measure, it was possible to achieve download speeds approaching 1 Gb/s and upload speeds of up to 200 Mb/s even in a completely full arena (approx. 17–18,000 spectators). Another example is one of the first standalone 5G networks, which the operator T-Mobile built primarily for industrial use on the CTU campus in Prague[23] .
    - “Cells on Wheels” – mobile base stations deployed in areas with (temporary) high demand for connectivity. It was these mobile base stations that enabled stable and fast connectivity to be provided in the aforementioned cultural and sporting events. For example, T-Mobile reports that by deploying three mobile base stations at the Colours of Ostrava festival, it was possible to achieve an average download speed of 285 Mbps despite the high concentration of visitors. A similar solution was also installed by Vodafone during the Karlovy Vary Film Festival.
- Other technical measures include, for example, network slicing technology, which can be applied in SA networks. This is a key technology that enables providers to create virtual networks (‘slices’) for specific types of services or applications – and to optimise them for those services. This makes it possible to utilise the infrastructure more efficiently and, moreover, to ensure both greater security and the stability and resilience of key services against potential outages[24] . This technology was, for example, utilised by the German operator Deutsche Telekom during the recent European Football Championship, when a dedicated 5G network was created for wireless television cameras and microphones in the stadiums[25] .

[22] https://mobilmania.zive.cz/clanky/operator-posilil-mobilni-sit-kvuli-hokeji-v-zaplnene-o2-arene-muzete-stahovat-rychlosti-az-800-mbit/s/sc-3-a-1360063/default.aspx, https://www.lupa.cz/clanky/gigabit-na-hokeji-podivejte-se-jak-byla-pred-mistrovstvim-sveta-modernizovana-mobilni-sit-v-o2-arene/

[23] https://www.ciirc.cvut.cz/cs/campus-network/, https://mobilenet.cz/clanky/t-mobile-v-praze-spustil-jeden-z-prvnich-ryzich-5g-kampusu-pro-prumysl-v-evrope-44266

[24] For further details, see, for example, https://cradlepoint.com/resources/blog/what-is-5g-standalone-5g-sa-means-network-slicing-security-and-automation/ or https://nybsys.com/5g-network-slicing/ and others.

[25] https://www.mobileworldlive.com/deutsche-telekom/dt-boosts-rtl-euro-2024-broadcast-with-private-5g/

**Summary of the chapter and conclusion**

There is insufficient robust data on connection quality parameters available for analysis; the assessment must therefore be based on several partial sources, such as ad-hoc measurements (which are, however, usually commissioned by operators, which inevitably distorts their informative value), data from measurements on motorways and major roads, or independent data produced by users of the NetTest application (which was developed and is operated by the Czech Telecommunications Office; the data can therefore be considered reliable).

Of the ad-hoc measurements presented by operators, O2 is the most active, carrying out measurements in collaboration with the Czech Technical University (ČVUT) and claiming that it achieves significantly better results than the other two operators in terms of quality parameters such as download and upload speeds or latency. The average download speed is said to reach almost 300 Mbps, which is almost double that of the other two operators. The operator attributes this difference primarily to the fact that, although its 5G network has lower population coverage, it is provided significantly more often in the 3.4–3.8 GHz frequency band, where higher speeds and network capacity are achieved. A similar conclusion is also suggested by the measurement results of the NetTest app, which
also ranks O2 first in terms of both speed and latency, though the gap between it and the other two operators is smaller. However, it is important to bear in mind the limitations of the NetTest data analysis, caused by the quality and quantity of the available data. The average download speed in the Czech Republic, according to NetTest data, exceeds 200 Mb/s; however, it should be noted that, to eliminate potential distortions, only those measurements taken in situations with a very strong signal. Conversely, data from measurements on motorways and major roads carried out by CTU staff place the operator O2 in last place in terms of download speeds. This difference is partly due to poorer 5G network coverage in the case of this operator.

Data from the NetTest app can also be used to some extent for an indicative comparison of the difference in the quality parameters of 5G network connections in urban and rural areas. The difference is, of course, significant; according to the analysis results, connections in cities are up to half as fast again as in rural areas, and lower latency values are also achieved.
At the same time, however, there is no direct correlation – connection quality does not decrease in direct proportion to the size of the settlement; other parameters are more decisive (distance from a larger urban area, geomorphological characteristics of the territory, etc.). It must be noted, however, that the use of NetTest data has limited interpretative possibilities due to the number of data inputs that can be
, as well as other limitations, primarily related to the fact that the data is generated by the users themselves when performing the connection test. The results of the analysis thus suggest trends rather than providing robust conclusions.

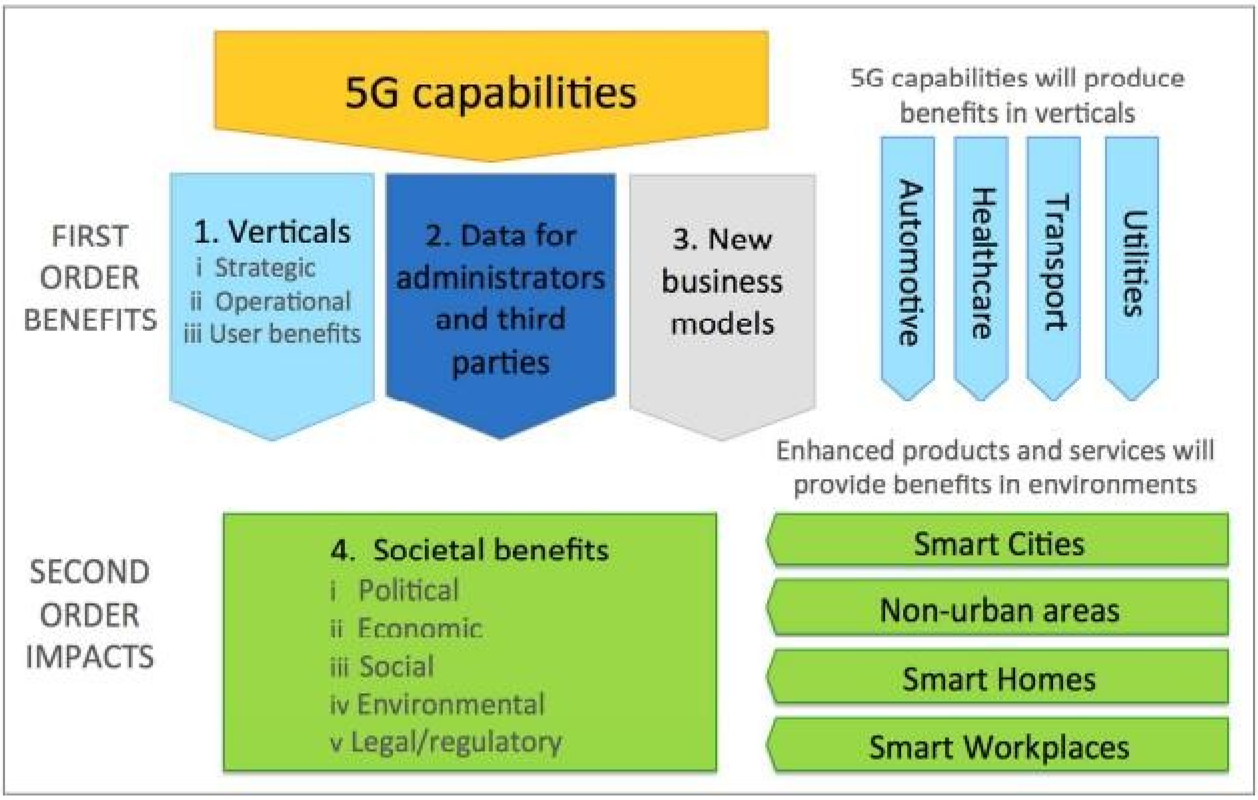
Connections to 5G networks appear to be more stable and of higher quality even in high-load situations (i.e. primarily high concentrations of people) compared to older technologies; however, even with 5G networks, connection quality drops significantly once a certain threshold of connected users is reached (all the more so when low-frequency bands are used). Operators in the Czech Republic and
Europe are addressing these limitations (whilst at the same time observing a trend of significantly increased demand for high-quality connectivity compared to the past, or higher data traffic volumes during events with high concentrations of people) by deploying mobile base stations or significantly upgrading infrastructure in stadiums, concert halls and other locations where high concentrations of users can be regularly expected. However, the full potential of 5G networks for managing such situations can only be realised through the application of 'stand-alone' technology.

# 6 Socio-economic benefits of 5G networks

## 6.1 Quantification of (socio)economic benefits

Estimates of the socio-economic impacts of 5G network development have been produced in a number of secondary studies, which use various methodologies for quantification. As early as 2017, the European Commission[26]estimated the economic benefits of the roll-out and development of 5G networks in four key strategic sectors (automotive, healthcare, transport and energy) at approximately €113 billion per year and the creation of approximately 2.3 million jobs. These estimates were compiled on the basis of expert assessments during workshops and a subsequent robust input-output analysis of modelled scenarios; the authors describe these estimates as rather conservative. Socio-economic benefits are defined as first-order (direct) and second-order (indirect) benefits. First-order benefits are estimated at approximately €62.5 billion per year, whilst second-order benefits amount to approximately €50.6 billion per year, according to the EC's 2017 model. For a more detailed breakdown of the benefits, see the diagram below:

*Figure 22: Benefits and impacts of the roll-out and development of 5G networks according to the EC's 2017 model*



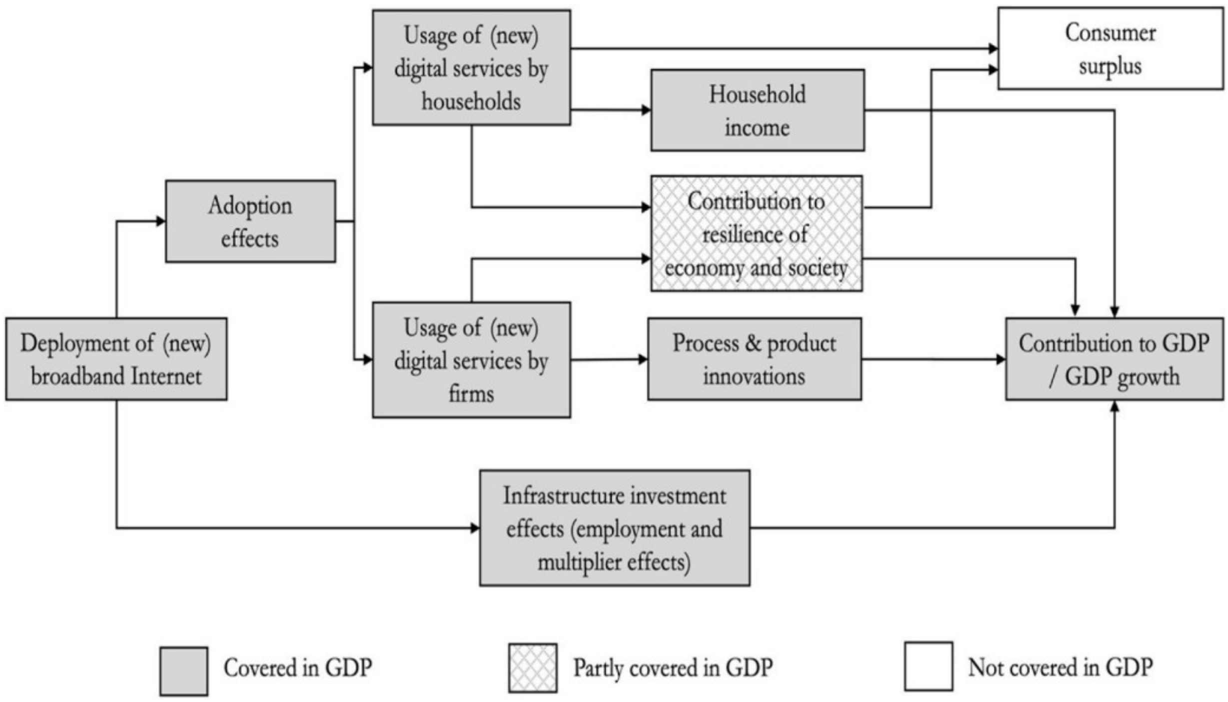

*Source: European Commission 2017.*

[26] European Commission: *Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe*, 2017

The key beneficiaries of these vertical and secondary benefits are expected to be businesses (€62.2 billion), consumers and society more generally (€37.1 billion) and 'third parties' – public administration, etc. (€13.8 billion).

The European Court of Auditors' 2021 report quantifies the potential benefits primarily in terms of the contribution of the roll-out and development of 5G networks to the EU's total GDP between 2021 and 2025, which it estimates at up to EUR 1 trillion, whilst up to 20 million jobs are expected to be created or transformed[27] . The mechanism by which the development of 5G networks, or high-speed internet connectivity more generally, contributes to socio-economic growth – expressed, among other things, by the contribution of this technology's development to GDP – is theoretically elaborated, for example, by Briglauer in his 2024 study[28] :

*Figure 23 Diagram of the economic impacts of the development of 5G networks / high-speed internet.*




*Source: Briglauer et al. 2024: 6.*

The diagram illustrates the complexity of the socio-economic impacts that are taken into account in studies aimed at quantifying them.

In the aforementioned estimate of the impact of the introduction and development of 5G networks on GDP and employment, the cited ECA report relies primarily on Accenture's analysis of the impact of 5G networks on the EU economy[29] . This analysis estimates that, as a direct result of the roll-out and expansion of 5G technologies, aggregate revenue (or gross output) in the EU economy will increase by approximately €2 trillion between 2021 and 2025. Several economic modelling methods were used to estimate these effects, including the use of historical data on the economic impacts of the introduction of previous generations of mobile networks. Furthermore, input-output modelling is also used, which tracks the flow of goods and services between sectors in the economy, thereby enabling the quantification of the impacts of changes in one sector on other sectors of the economy, as well as other economic models utilising dynamic panel data. The methodology also utilises an estimate of the multiplier effect of the impact of 5G technology deployment on the value chain (estimated value 2.0).

The detailed impacts of this projection on individual EU Member States (including the United Kingdom) are presented in the following cartogram:

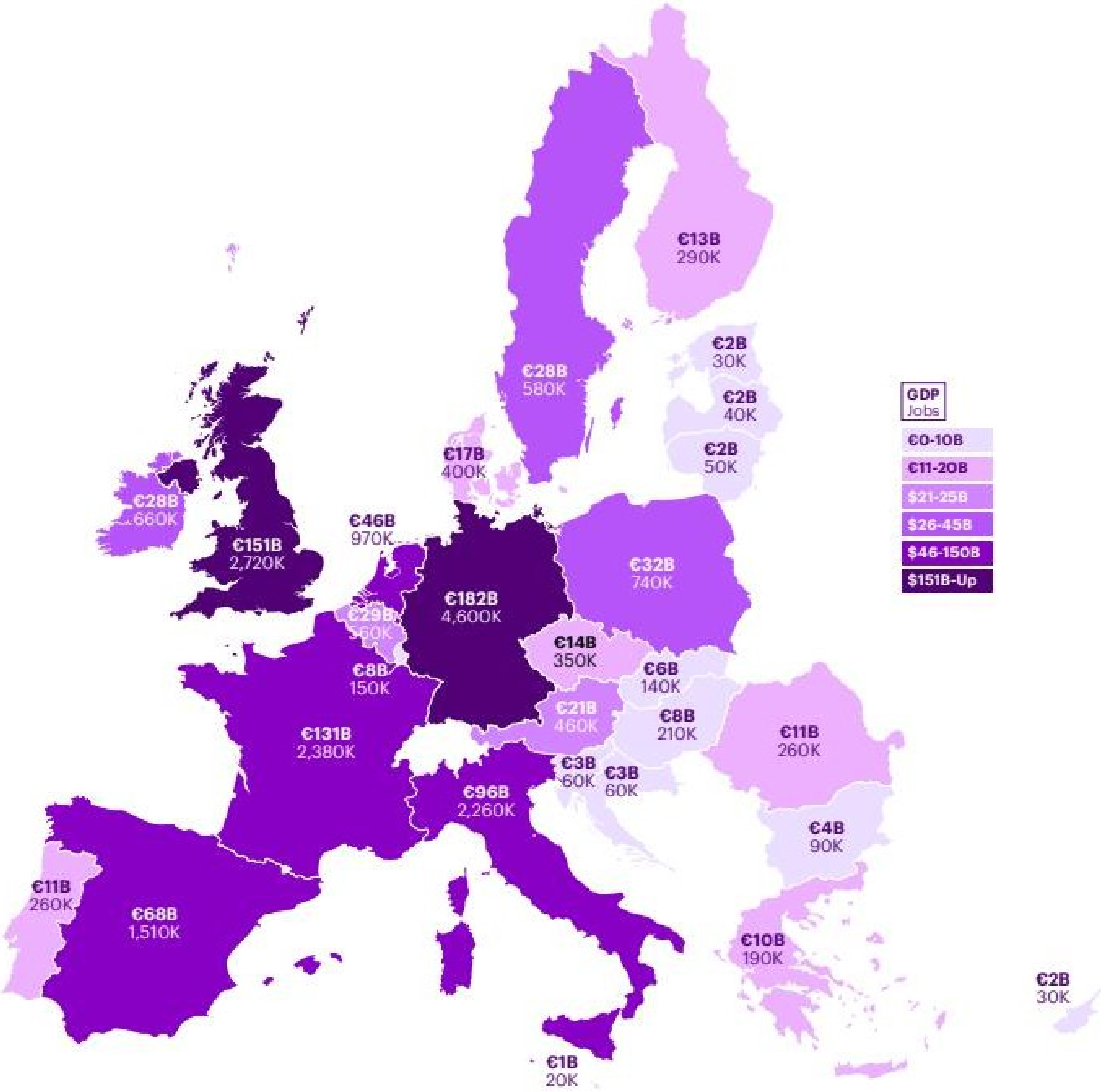
---

[27] European Court of Auditors: Special Report 03/2022 *'5G roll-out in the EU: delays in deployment of networks with security issues remaining unresolved*', 2022: 7–8.

[28] Briglauer, W. – Kraemer, J. – Palan, N. (2024): *Socioeconomic benefits of high-speed broadband availability and service adoption: A survey*, Telecommunications Policy 48(7).

[29] Accenture: *The Impact of 5G on the European Economy*, 2021.

*Figure 24 Estimated impact of 5G networks on GDP and jobs in individual countries*

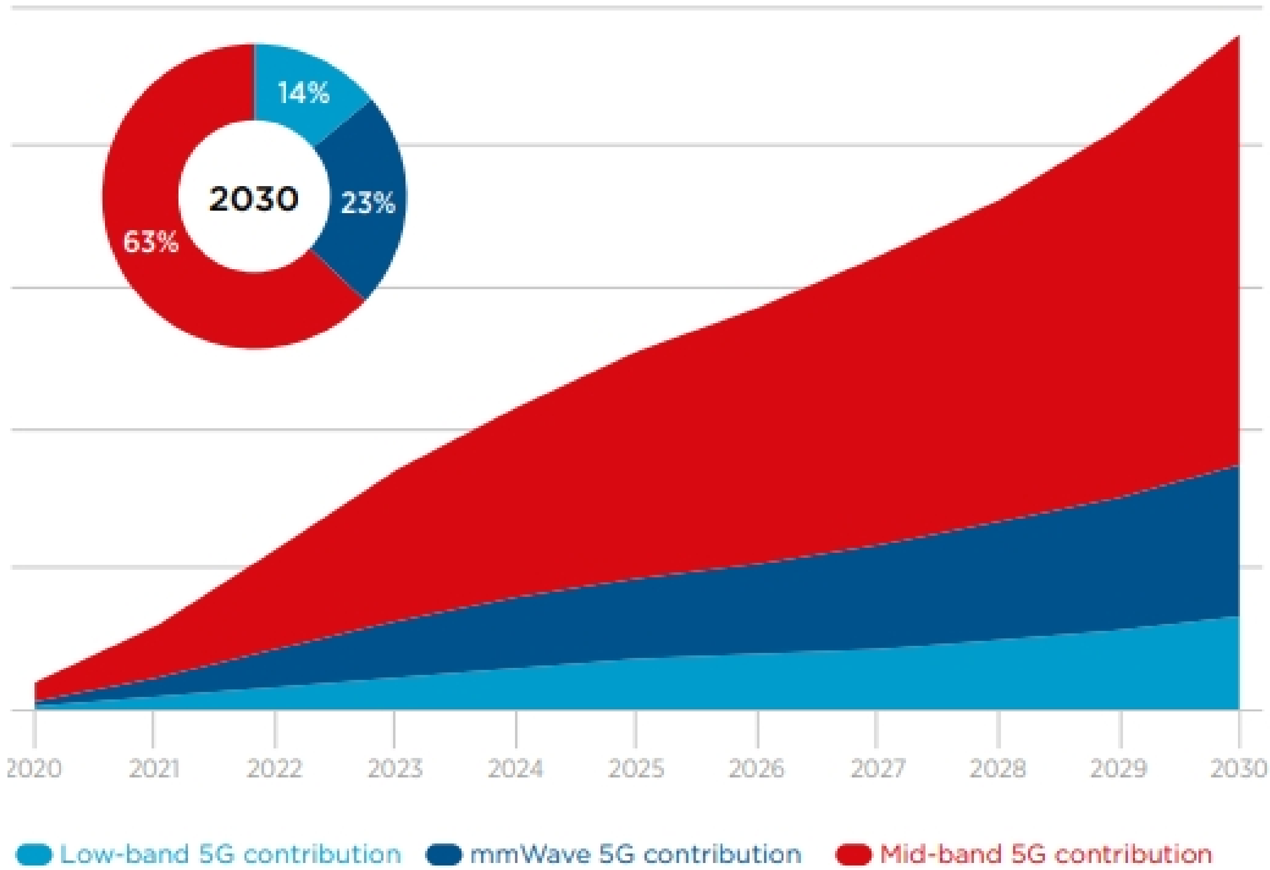



*Source: Accenture 2021: 75.*

The impacts of 5G network development on the Czech Republic's GDP are therefore estimated at approximately EUR 14 billion (by 2025) and are expected to create or transform up to 350,000 jobs (i.e. approximately 1.5–2% of the impacts estimated for the EU as a whole). Given the Czech Republic's total GDP, which stood at approximately EUR 220 billion in 2020, the estimated contribution amounts to up to 6.3% of this figure for the period 2021–2025 – this represents an average share, with the estimated contribution of 5G networks to GDP in most EU countries for the period 2021–2025 ranging from approximately 5.5–6.5% (the exceptions being Cyprus and Luxembourg, with approximately 9% and 12% respectively; a slightly lower share is, conversely, estimated in Lithuania or Romania).

A further perspective on the economic benefits of the roll-out and expansion of 5G networks is provided by a 2022 analysis by the Global System for Mobile Communications Association (GSMA)[30] . It estimates that the annual contribution of 5G technologies to global GDP will amount to USD 960 billion in 2032, thereby bringing about an additional increase in global GDP of approximately 0.7%. For further details, see the chart below:

*Figure 25 Annual impact of 5G technologies on global GDP, broken down by region*




*Source: GSMA 2022: 12.*

## 6.2 Socio-economic benefits by sector

The introduction and expansion of 5G technologies has the potential to significantly impact a range of sectors and areas of life. For this reason, a brief sectoral overview of the potential socio-economic benefits of 5G network expansion has been prepared.

30 GSMA: *The Socio-Economic Benefits of Mid-Band 5G Services*

*Figure 26 Diverse applications of 5G networks in a broader socio-economic context.*


*Source: European Commission*

In line with secondary sources, this overview is divided into the following sectors ('verticals'):

- Healthcare
- Agriculture
- Energy
- Transport and logistics
- Manufacturing
- Education

## 6.2.1 Healthcare

According to GSMA estimates, up to 11% of the benefits of 5G networks discussed above will be concentrated in the healthcare sector (in OECD countries)[31] . According to an analysis by Accenture (cited above), the roll-out and expansion of 5G networks in the healthcare sector has the potential to generate (between 2021 and 2025) up to €77 billion in additional revenue (an additional contribution of €51.2 billion to EU GDP) and create or transform up to 400,000 jobs.

The socio-economic benefits in the healthcare sector can be summarised as follows:

**Improved access to healthcare**

5G technologies can significantly improve access to healthcare, particularly in rural and remote areas where access to quality healthcare is limited. As noted in an analysis by Deetken Insight[32] , 5G technologies can expand telemedicine and remote diagnostics, enabling doctors to provide consultations and treatment to patients remotely via high-quality video streams and other digital tools. This can lead to reduced waiting times and increased availability of specialist care. This assessment is also confirmed by other analyses (see, for example, Accenture 2021: 47–48), which state that 5G will enable the provision of remote healthcare, thereby improving access to healthcare for patients living in remote areas or with limited mobility.

[31] See: GSMA: *5G and economic growth – an assessment of GDP impacts in Canada*, 2020.

[32] Deetken Insight: *The Socio-Economic Impacts of 5G*, 2022.

Furthermore, it will enable fast and efficient communication between patients and healthcare staff, which can improve treatment outcomes and reduce the need for physical visits to hospitals.

**Improving healthcare efficiency**

5G technology can help improve healthcare efficiency by integrating various digital technologies, such as IoT (Internet of Things) devices, which can monitor patients' health in real time and send data directly to healthcare professionals. This enables faster and more accurate treatment decisions and can lead to a reduction in hospitalisation costs. Furthermore, faster transmission of large volumes of data is key to the implementation of AI applications and machine learning in healthcare. These technologies can assist in the analysis of health data and provide doctors with better tools for diagnosing and treating diseases.

**Innovation and new technologies**

The development of 5G technologies is driving the development of innovative solutions in the field of healthcare technology, including the development of new devices and applications for healthcare. For example, augmented reality (AR) and virtual reality (VR) can be used for training healthcare staff and for surgical operations using remotely controlled robots. Furthermore, an analysis by Accenture states that 5G will also enable the development of 'smart ambulances' equipped with advanced diagnostic tools that can transmit health data in real time to hospitals. This can improve emergency care and reduce response times to critical medical situations.

**Improved treatment outcomes and patient experience**

The authors of the Deetken study (see above) note that thanks to 5G, patients can expect higher quality of care and better treatment outcomes. Timely access to medical consultations and real-time monitoring can lead to better management of chronic conditions and a reduction in the number of hospital admissions. Thanks to 5G, patients will have better access to information about their health and treatment, which will potentially increase their involvement in their own healthcare and improve the overall patient experience.

## 6.2.2 Energy

The energy sector is another key sector set to benefit significantly from the roll-out of 5G networks. An Accenture study (see above) estimates that the benefits of introducing 5G technologies in the broader 'utilities' sector – which it primarily analyses as the value chain of electricity generation and distribution – will amount to approximately €74 billion in additional revenue in the EU between 2021 and 2025.

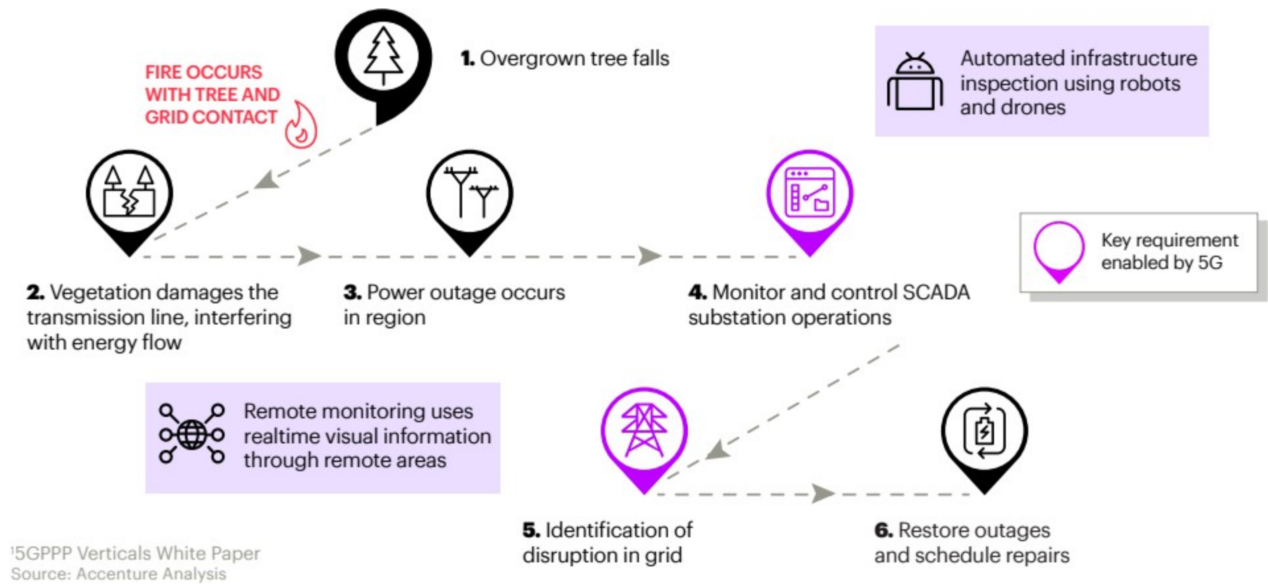
These benefits are spread across the entire value chain. Specifically, the following socio-economic benefits in the energy sector can be identified:

*Figure 27*

**Improved efficiency and productivity** 5G technology enables advanced automation and digitalisation of energy infrastructure. This includes the deployment of smart sensors and real-time monitoring systems, which can significantly increase operational efficiency and productivity. The use of 5G will enable more precise management of energy consumption and the optimisation of production and distribution, leading to reduced costs and increased reliability of energy supply (see, for example, Deetken 2022: 61–64).

**Smart Grids** 5G technology is key to the development of smart grids, which improve energy management and distribution. Smart grids enable better integration of renewable energy sources, contributing to the sustainability of energy systems. 5G provides the necessary connectivity for the widespread deployment of smart meters, which enable real-time collection and analysis of energy consumption data, helping to optimise energy use and reduce production and distribution costs. For potential applications of 5G technology in the context of Smart Grids, see the following diagram:

*Figure 28 'Use Case Journey' of smart distribution systems*




*Source: Accenture 2021: 55*

**Emissions reduction and energy efficiency** The implementation of 5G technologies in the energy sector has the potential to contribute to a reduction in greenhouse gas emissions. For example, smart grids and meters will enable better monitoring and management of energy consumption, leading to the optimisation of energy production and a reduction in energy losses.

**Safety and reliability** 5G technology can improve the safety and reliability of energy systems. Thanks to low latency and high data transmission capacity, energy companies will be able to respond more quickly to outages and other emergency situations. This includes faster detection and repair of faults in the distribution network, which minimises downtime and increases the reliability of energy supply (cf. e.g. European Commission 2022: 96–99; see also other sources).

**Supporting the new workforce** 5G technology will enable remote management and monitoring of energy infrastructure, reducing the need for staff to be physically present in the field. As noted in an analysis by Accenture, this is particularly important given the ageing workforce in the energy sector. Modern tools and technologies will enable more effective training and deployment of a new generation of workers, who will be equipped with the skills needed to manage and maintain advanced energy systems.

**New business models** 5G technology opens the door to new business models, such as 'energy as a service'. This model will enable energy companies to offer customers comprehensive packages of energy solutions instead of the traditional sale of electricity. Customers will thus be able to pay for specific services, such as heating, cooling or the operation of household appliances, which increases the flexibility and value of the services provided.

## 6.2.3 Agriculture

A number of secondary sources indicate a significant expected impact of the introduction of 5G technologies in the agricultural sector. For example, a 2021 report by Cambridge Econometrics[33] states that 5G technologies will also make a significant contribution to the rural sector, as they will enable better monitoring of crop and livestock production – the benefits of 5G technologies will thus include higher agricultural yields, lower costs of (veterinary) livestock care, reduced costs and, at the same time, positive environmental impacts thanks to more efficient use of pesticides and other products, etc. (cf. Cambridge Econometrics et al. 2021: 36). According to the GSMA report, agriculture in developed countries is expected to account for approximately 1% of all (socio-)economic benefits of the introduction of 5G technologies,

[33] Cambridge Econometrics and Analysys Mason: *Realising the Benefits of 5G – A report for the Department for Digital, Culture, Media and Sport*, 2021.

Accenture, meanwhile, forecasts approximately €50 billion in additional revenue for the EU agricultural sector between 2021 and 2025 thanks to the introduction and development of 5G technologies, as well as the creation or transformation of approximately 300,000 jobs.

The specific expected socio-economic benefits of 5G technologies in agriculture can be summarised as follows:

**The development of precision farming and increased productivity.** 5G will enable the rapid development of advanced precision farming techniques, which will increase the efficiency of resource use and crop yields. For example, sensor networks and IoT devices will provide real-time data on soil conditions, enabling the precise application of fertilisers and pesticides. This can lead to increased productivity and reduced costs. According to an Accenture study, the use of 5G in agriculture can increase yields by up to 25% and reduce water and energy costs (cf. Accenture 2021: 61–64). The benefits of precision farming, made possible by 5G technologies, in reducing the amount of pesticides, fertilisers, herbicides and other substances applied are estimated to be in the tens of per cent. Empirical analyses then show that the introduction and development of precision farming leads to a demonstrable increase in productivity of up to 10% [34].

**Automation using drones.** Drones equipped with 5G technology will enable the monitoring of crops and livestock and the automatic/autonomous implementation of precision agricultural interventions (see Deetken 2022: 52). These drones can pinpoint problem areas in fields and apply fertilisers and pesticides up to 60 times faster than manual methods (see Accenture 2021: 62).

**Smart greenhouses.** Using 5G, IoT and connected devices, smart greenhouses will be able to create a self-regulating microclimate that optimises crop growth and reduces the impact of adverse conditions and predators.

**Increased productivity whilst reducing manual labour**. Labour shortages in agriculture are a major limiting factor. According to some estimates, up to a third of farmers are switching to less labour-intensive production methods due to the limited supply of labour (Accenture 2021: 62–63). The development of technologies reliant on 5G connectivity will reduce the need for manual labour whilst creating new jobs in data analysis and smart farm management.

### 6.2.4 Transport and Logistics

The development of 5G technology in the transport and logistics sector will have a significant impact – thanks to improved connectivity across all areas of transport and logistics, particularly with regard to autonomous systems. The development of connectivity also has a positive impact on transport efficiency and improves traffic flow. Operational efficiency in transport (particularly freight transport) will also increase thanks to the availability of real-time data on freight transport capacity[35] - In its report, the European Commission estimates that in the field of road freight transport alone, the introduction of 5G technologies will generate more than €8 billion annually (see European Commission 2017: 63).

The specific benefits can be summarised as follows:

**Smart transport.** 5G will enable efficient traffic management and the reduction of traffic congestion through smart transport systems that analyse data in real time. This can lead to improved traffic flow and reduced journey times
.

**Autonomous vehicles.** Thanks to 5G, autonomous vehicles will be able to communicate with each other and with urban infrastructure, thereby increasing their safety and efficiency. This also includes improvements in logistics, where autonomous lorries can reduce transport costs and increase delivery efficiency.

**Smart warehouses.** In warehouses, 5G technology will enable better inventory management through robotics and IoT devices that optimise storage, stock control and goods dispatch. This can lead to faster order processing and reduced storage costs. The introduction of these fundamental innovations in logistics cannot be achieved without 5G technologies, which enable the integration of digital solutions and specific technologies such as smart sensors or robotic solutions (cf. Deetken 2022: 82–83).

---

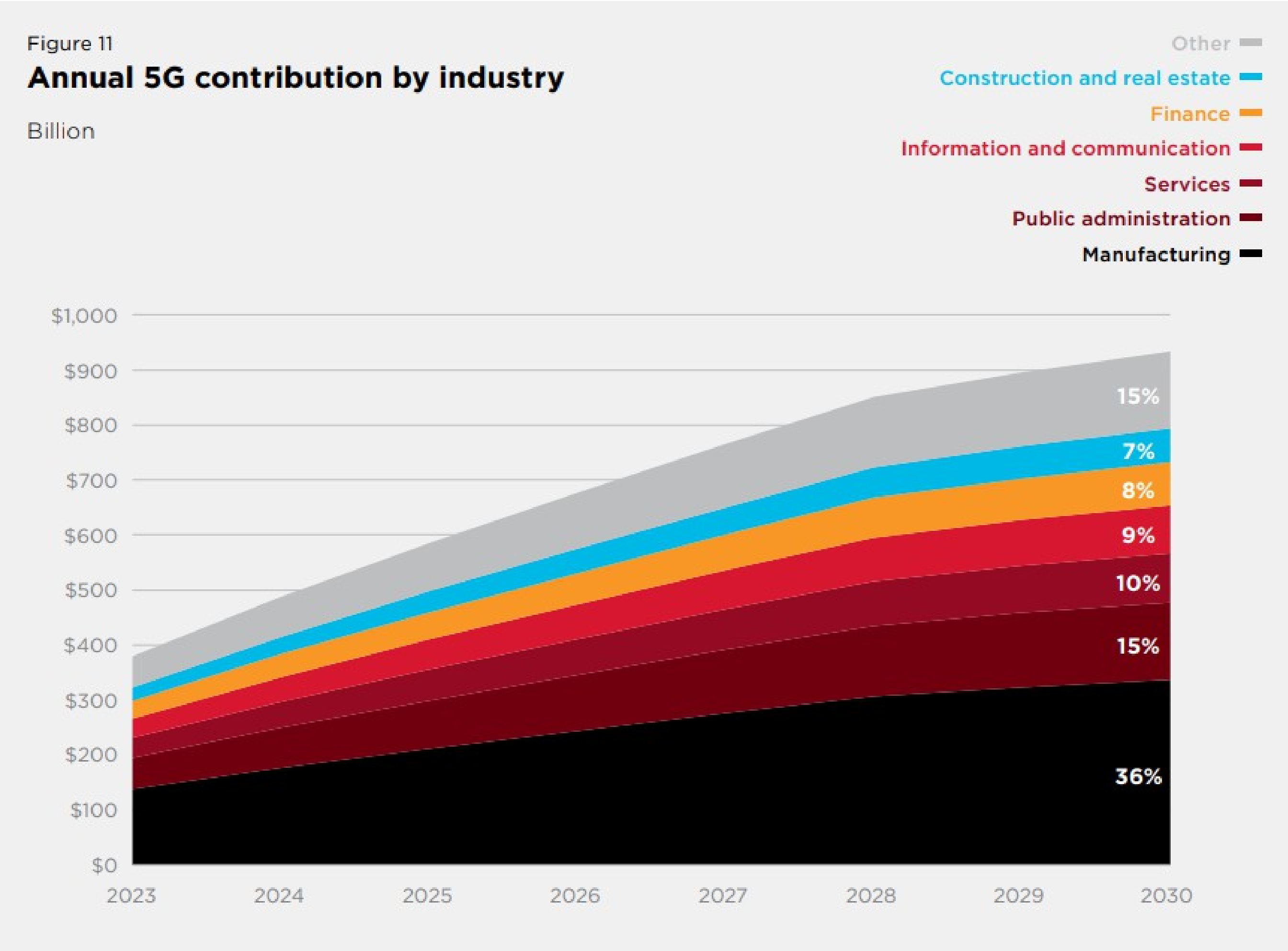
[34] See, for example, AEM et al.: *The Environmental Benefits of Precision Agriculture in the United States*, undated.

[35] As stated in the final report of the European Platform Driving Knowledge to Innovation in Freight Logistics project, supported by the EU's Seventh Framework Programme, inefficiencies in road freight transport (for example, up to a quarter of lorries travel empty, lorries are on average only 57% loaded, etc.) generate losses of up to EUR 160 billion a year. See https://cordis.europa.eu/project/id/314743/reporting.

### 6.2.5 Manufacturing

In the field of industrial manufacturing, according to a GSMA analysis, this sector stands to benefit the most from the roll-out and expansion of 5G technologies, as shown in the following chart:

*Figure 29 Contribution of 5G technologies to the global economy by sector*




*Source: GSMA 2024: 20*[36]

According to the Accenture analysis cited several times above, 5G technologies will contribute to an increase in revenue in EU economies of almost €460 billion between 2021 and 2025 and create or transform up to 5.4 million jobs. Even from the perspective of this analysis, the impact of 5G technologies in the industrial manufacturing sector is dominant – accounting for approximately 23% of the total expected additional revenue generated by 5G technologies and up to 27% of new or transformed jobs. The specific socio-economic impacts of 5G technologies in industrial manufacturing are highly diverse and can be categorised as follows:

**IoT in industry**. 5G networks will enable the widespread deployment of IoT technologies, where connected devices and sensors will allow for real-time monitoring of production processes. This will lead to increased productivity, reduced downtime and the optimisation of production lines. The development of IoT will also enable the automation of processes in the procurement of supplies and production inputs and their management within the production process, which will reduce both input and inventory costs, as well as energy consumption, transport and storage costs, etc. In addition to economic benefits, environmental benefits of the introduction of 5G technologies in this context are also observed (cf. e.g. Deetken 2022: 67–68).

[36] GSMA: *The Mobile Economy 2024*, 2024.

**Predictive maintenance** (“Intelligent Asset Management”)**.** Thanks to rapid data transmission, 5G will enable predictive maintenance of machinery, thereby reducing downtime and extending the service life of production equipment. Sensors can detect and report problems even before they arise, thus preventing unplanned downtime and the economic losses it generates. The development of connectivity enabled by 5G technologies will facilitate the expansion of AI solutions for predicting defects and the remaining service life of production assets, which will not only lead to the aforementioned reduction in losses caused by unplanned downtime, but will also enable maintenance planning to minimise the impact on both costs and production.

**Automation and robotics.** Greater connectivity will enable advanced control of robotic systems and automated production processes, thereby increasing the flexibility and adaptability of production to changing market demands. An analysis by Accenture in this context states that the development of automation and robotics will bring a 20–30% increase in productivity and a one-third increase in production efficiency (Accenture 2021: 31).

Other socio-economic benefits highlighted in secondary sources include, for example, the introduction of augmented reality and the associated use of ‘remote experts’, improved employee safety[37] (e.g. remote inspections in hazardous environments), increased efficiency in employee training and education, and improved quality control (see Cambridge Economics et al 2021: 37).

## 6.2.6 Education

In the field of education, 5G technology will enable the development of a range of innovations that improve the quality and accessibility of education, e.g.:

**Virtual and augmented reality (VR/AR).** 5G will enable the widespread use of VR and AR in teaching, leading to more interactive and engaging learning. Students can use these technologies to better understand complex concepts and gain practical experience in a safe environment (for more details, see Deetken 2022: 78).

**Artificial intelligence (AI).** AI, combined with 5G, can provide personalised support to students, analyse their progress and suggest appropriate teaching methods and projects, thereby increasing student success and retention rates.

**Better access to education.** Thanks to 5G, high-quality education will become more accessible even in remote and underfunded areas, thereby reducing the digital divide and increasing the chances of success for all students[38] .

[37] For example, Lockheed Martin’s specific experience indicates that the introduction of augmented/virtual reality reduced the incidence of workplace accidents by 5–15%; see the article “Lockheed Martin Embraces AR on the Factory Floor”, https://www.assemblymag.com/articles/95163-lockheed-martin-embraces-ar-on-the-factory-floor

[38] For further details, see, for example, the World Bank’s analysis in the article ‘How can 5G make a difference to education?’ (https://blogs.worldbank.org/en/digital-development/how-can-5g-make-difference-education)

**Summary of the chapter and conclusion**

The socio-economic benefits of 5G networks are primarily assessed in terms of their impact on gross domestic product (GDP), employment and economic benefits across various sectors.

As early as 2017, the European Commission estimated that in four key strategic sectors (automotive, healthcare, transport and energy), the annual economic benefit could reach up to €113 billion, with the creation of approximately 23 million jobs expected. Other sources also agree on the significant contribution of 5G network development in terms of both GDP and jobs. A 2021 report by the European Court of Auditors, citing estimates from Accenture, for example, states that the roll-out and development of 5G networks could contribute up to €1 trillion to the EU's total GDP between 2021 and 2025 and create or transform up to 20 million jobs. The analyses use various economic models, including input-output modelling, which tracks the flow of goods and services between sectors of the economy, and dynamic panel data.

5G technologies offer specific benefits in particular sectors. In agriculture, they can increase yields by up to 25% and reduce water and energy costs. Benefits in agriculture include the development of precision farming, increased productivity, cost reductions and positive environmental impacts. The development of 5G networks has the potential to deliver significant economic impacts in other sectors as well, to foster innovation and to improve quality of life. These benefits are comprehensive and encompass both direct economic impacts and broader socio-economic effects that contribute to the growth and competitiveness of the European economy.

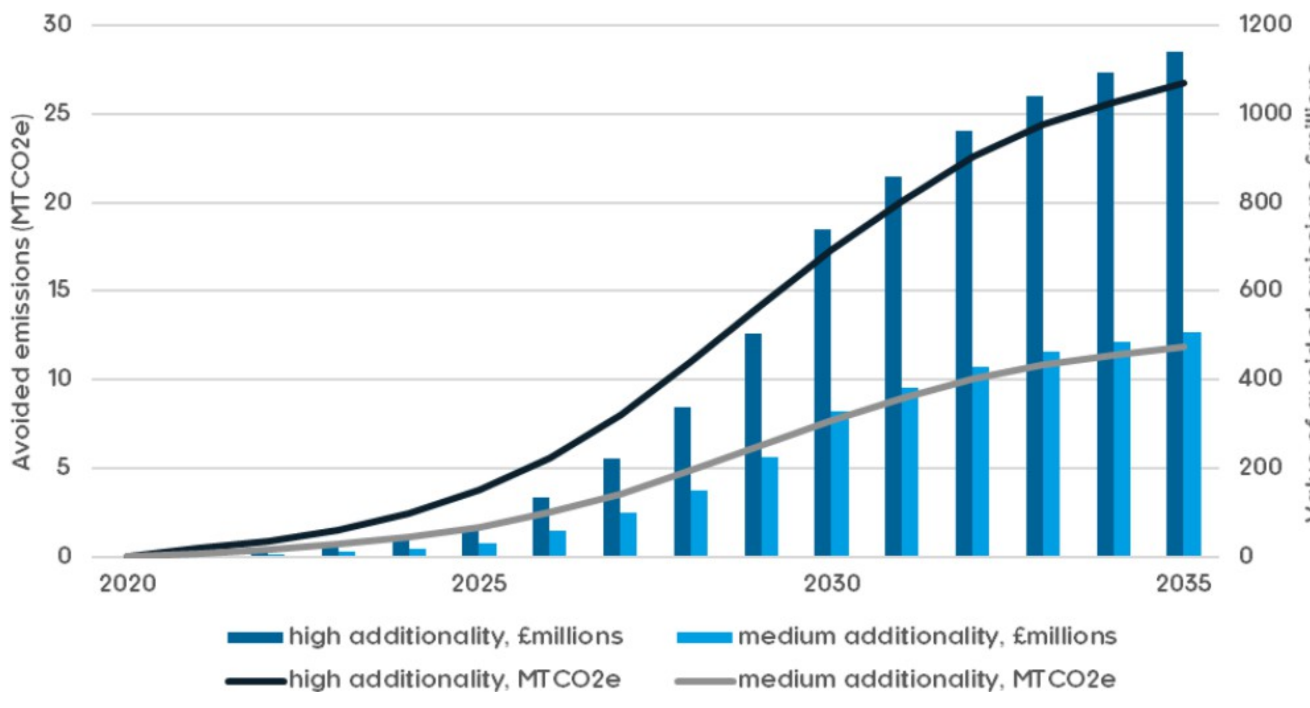
# 7 The environmental context of expanding 5G networks

The environmental impacts of expanding 5G network coverage have already been partially addressed in the text above, in the assessment of socio-economic benefits. Among the positive effects of expanding 5G network coverage, secondary sources highlight the following in particular:

**Reduction in greenhouse gas (GHG) emissions:**

5G technology can contribute to a significant reduction in greenhouse gas emissions. For example, the use of IoT sensors in agriculture can optimise the consumption of water, energy and fertilisers, leading to lower emissions of $CO_2$ and other GHGs. According to a model by Cambridge Analytics, the development of 5G technology in the UK could result in $^{CO_2}$ emissions savings of up to 27 million tonnes of carbon dioxide equivalent (mtCO2e) by 2035 and, in total, up to 184 million tonnes $^{\text{of CO2}}$ equivalent between 2021 and 2035 under an optimistic scenario. (see Cambridge Analytics 2021: 118–123).

*Figure 30: Model projecting CO2 savings resulting from the roll-out of 5G technologies in the UK*




*Source: Cambridge Analytics 2021: 120.*

In this context, a study by Deetken states that in the agricultural sector, 5G technologies can reduce emissions by up to 15–25% (cf. Deetken 2022) and further elaborates that in the Canadian context (for which it was primarily prepared), greenhouse gas emission savings achieved through the development of 5G technologies could reach up to 54 metric tonnes of CO2 equivalent (MtCO2e), i.e. a reduction of up to 20%. Key sectors contributing to this include smart work, living and health technologies

(29%), smart transport and cities (24%), smart manufacturing (18%), smart buildings (16%), smart agriculture (7%) and smart energy (5%)[39] .

Other effects of 5G technology development on reducing GHG emissions include, for example:

- Intelligent traffic management systems: Technologies such as vehicle platooning (groups of vehicles travelling together) can reduce CO2 emissions by 10% to 30% by improving aerodynamic drag and optimising distances between vehicles
- Smart public transport and ride-sharing: Emissions per person on public transport are approximately 53% lower compared to driving or ride-sharing alone. 5G will enable better monitoring and optimisation of public transport, which will increase its usage and reduce energy consumption
- Energy efficiency in buildings: 5G enables smart buildings to use IoT devices to monitor and control heating, cooling and lighting systems in real time. This can lead to significant energy savings and lower greenhouse gas emissions
- Better coordination of logistics operations

**More efficient use of resources in industry and households**:

5G enables more accurate monitoring and management of energy consumption and other resources. For example, smart energy meters can reduce energy consumption in homes and businesses, leading to lower $CO_2$ emissions. According to the European Commission, smart meters in households with 5G connectivity could deliver environmental benefits of approximately €609 million by 2025 (European Commission 2017: 79). As regards the 'smart workplace' – that is, the more efficient use of energy resources whilst (primarily) reducing waste production through the roll-out of 5G technologies – the European Commission estimates that their development could generate environmental benefits of up to €16.1 billion per year in this context (ibid., p. 81).

**"Smart cities" and the development of sustainable urban mobility**

The integration of 5G in smart cities is expected to significantly reduce pollution through improved traffic management and the deployment of smart meters. These technologies can lead to reduced energy consumption and thus lower GHG emissions. 5G technologies can support the development of smart urban mobility, such as autonomous vehicles and intelligent transport systems, which optimise transport and reduce traffic congestion, leading to lower fuel consumption and reduced exhaust emissions.

However, the development of 5G technologies and, more generally, the expansion of 5G network coverage can also have negative environmental impacts. Among the most significant, the following must be mentioned in particular:

- Higher network energy consumption: Although 5G networks may be more energy-efficient in operation, the construction and maintenance of extensive 5G infrastructure (including base stations and new equipment) can lead to increased energy consumption and emissions associated with the manufacture and installation of this equipment. This is a consequence of the dense network of small base stations required to ensure the coverage and capacity of 5G networks. Although 5G technology may be more energy-efficient in terms of data transmission per bit, overall energy consumption may increase due to the greater number of stations and higher operational and maintenance requirements. Thus, 5G technology can be up to 90% more efficient in terms of energy consumption per unit of traffic (W/Mbps)[40] compared to 4G – primarily thanks to more efficient technology, more energy-efficient antennas and the systematic use of energy-saving algorithms (Chochliouros et al. 2021[41] :6). However, overall energy consumption may still rise due to the need for a much larger number of small cells to achieve the required capacity – and this is also in the context of

[39] Cf. Deetken 2022: 95–97.

[40] See, for example, https://www.viavisolutions.com/en-us/resources/learning-center/what-5g-energy-consumption or https://www.telecompetitor.com/study-5g-has-90-better-energy-efficiency-than-4g/ ; similarly, see also Deetken 2022: 94.

[41] Chochliouros, I.P. et al. (2021): *Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures* – the article analyses sources of energy savings in 5G technologies in great detail.

use of higher frequency bands[42] . This infrastructure requires more equipment, which increases overall energy consumption[43] .

- Environmental costs of manufacturing and installing 5G technologies: the manufacture and installation of new equipment for 5G networks involves the extraction of raw materials, manufacturing and logistics, which can have negative environmental impacts, including increased emissions of $CO_2$ and other harmful substances
- Electromagnetic radiation: Existing concerns about increased electromagnetic radiation caused by a denser network of small cells and devices using 5G connectivity may, as specific cases cited in the Accenture study show, lead to restrictions on infrastructure development due to safety zones around 5G network transmitters – these often prevent the densification of 5G infrastructure in densely populated areas (conurbations); see Accenture 2021: 66.
- E-waste: The expansion of 5G technologies will lead to increased production of electronic waste – a wide variety of devices and sensors using 5G technology that will be progressively replaced or reach the end of their service life.

**Summary of the chapter and conclusion**

5G networks offer increased data transmission efficiency, leading to energy savings per unit of transmission. However, overall energy consumption may increase due to the need for a dense network of small base stations. These stations, essential for ensuring coverage and capacity, increase the network's overall energy intensity.

In addition to energy aspects, environmental costs are also associated with the manufacture and installation of new equipment, which includes raw material extraction, production and logistics. These processes can lead to higher CO2 emissions and the generation of electronic waste. There are also concerns about increased electromagnetic radiation caused by a dense network of small cells, which may lead to restrictions on infrastructure development.

[42] An analysis by Accenture states that, particularly in higher frequency bands, a 5G network will require 10 to 100 times more transmitters than previous 4G technology – due to the shorter range in higher frequency bands and their reduced ability to penetrate obstacles. See Accenture 2021: 66.

[43] A similar conclusion is reached in the report 'Environmentally Sustainable 5G Deployment' published by InterDigital and ABI Research, which states that the development of 5G technologies will lead to an increase in energy consumption of up to 160% by 2030. See https://go.abiresearch.com/lp-environmentally-sustainable-5g-deployment.