Study

Economic Effects of 5G Infrastructure Development in the Republic of Croatia

Institute of Economics, Zagreb

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ABOUT AUTHORS

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The Institute of Economics, Zagreb (EIZ) is a public scientific institute with over 80 years of experience in scientific and development research in economics. It was founded in 1939 and today has the reputation of being the leading institute for economic research in Croatia. EIZ conducts research in four broad areas: macroeconomics and international economics, business economics and economic sectors, regional development, social policy, and the labor market. Within the research area of business economics and economic sectors, EIZ also covers topics related to digital transformation and digital infrastructure, in which it has participated in several research projects for the the European Commission, Hrvatski Telekom, SAP, Ernst & Young, Deutsche Telekom, and Croatian Employers Association.

The survey was prepared by Maruška Vizek, PhD as research leader, Tajana Barbić, PhD, Davor Mikulić, PhD, and Assoc. Prof. Nebojša Stojčić, PhD from the University of Dubrovnik as research team members. The case studies were prepared by Dragana Radusinović Tafra.

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Executive Summary

This study aims to assess the economic effects of 5G infrastructure development in the Republic of Croatia. To that effect, two complementary analyzes of the expected benefits of 5G network development were carried out. Based on the methodology and basic results presented in Analysys Mason (2020), in this study we present estimates of capital expenditures for the development of 5G infrastructure for four economic clusters: Smart Production and Logistics, Smart Rural, Smart Urban and Smart Public Services for all Croatian counties. The Smart Manufacturing and Logistics cluster includes the manufacturing industry, ports, airports, mining, and tourism as specific 5G infrastructure use cases. The Smart Rural cluster includes agriculture and fixed wireless access (FWA) as use cases, while the Smart Urban cluster includes development and hotspots). The obtained estimates of capital expenditures for 5G infrastructure development are then compared with the estimated discounted economic benefits from 5G infrastructure development for the period up to 2040 for these four clusters by counties to calculate the benefit-cost ratio from the introduction of 5G network and thus assessed the cost-effectiveness of investments in 5G infrastructure in individual clusters and Croatian regions. Since we apply the same methodology as Analysys Mason (2020), we can compare the results obtained for Croatia with other European Union countries. The results of the analysis suggest the following conclusions:

- The total benefits of investing in the 5G network in terms of net present value in the total Croatian economy are estimated at EUR 1.33 billion, three times more than investments costs which should amount to around EUR 445 million. The average benefit-cost ratio of investing in 5G infrastructure in the European Union is 4.3. Croatia is ranked 19th in the European Union with a ratio of 3.0 and can be classified in the group of countries that includes Estonia, Latvia, Greece, and Bulgaria, which have a slightly lower ratio than Croatia.

- The annual net benefit per capita from investments in 5G infrastructure is EUR 14.5 per capita, or 1.72 percent of GDP.

- The highest costs of investment in the development of 5G infrastructure in absolute terms are expected in the City of Zagreb, where they amount to EUR 60.2 million. Then follow

Primorje-Gorski Kotar County (EUR 47.9 million), Split-Dalmatia County (EUR 42.9 million) and Istria County with an expected investment of EUR 36.6 million. However, in GDP terms, the City of Zagreb records the lowest cost of investment in 5G infrastructure (only 0.3 percent of GDP), while the highest relative cost of investment is expected in Lika-Senj County (as much as 3.6 percent of GDP), then in Dubrovnik-Neretva County (1.5 percent), Istria County (1.2 percent of GDP) and Primorje-Gorski Kotar County (1.1 percent of GDP).

The largest amount of benefits with the most favorable benefit-cost ratio is expected in the Smart Rural cluster, where 4.3 times the amount of benefits is expected for each EUR of investment.

Net benefits from 5G infrastructure in the Smart Rural cluster are greatest in Bjelovar-Bilogora (3.7 percent of GDP), Koprivnica-Križevci (2.7 percent of GDP), Vukovar-Srijem, and Virovitica-Podravina County (2.5 percent of GDP).

In the Smart Manufacturing and Logistics cluster, benefits are expected in the amount of EUR 507 million, with the highest amount of required investments in infrastructure reaching EUR 228 million. This means that the long-term lag in the speed of acceptance of modern technological processes in the manufacturing industry compared to more advanced European countries results in a relatively low benefit-cost ratio of 2.2 in this cluster, lower compared to the other three clusters.

The highest ratio of benefits and costs from investing in 5G infrastructure in the Smart Manufacturing and Logistics cluster is expected in Istria County, where the ratio is 4.5, and above the national average are the City of Zagreb and Dubrovnik-Neretva County with a benefit-cost ratio of 3.5 and the Split-Dalmatia County with a benefit-cost of 2.5. Istria County also realizes the greatest benefit from investing in 5G in the Smart Manufacturing cluster, which amounts to 2.0 percent of GDP.

The biggest benefits from investing in 5G infrastructure in the Smart Manufacturing and Logistics cluster are expected for the manufacturing industry (EUR 256 million), tourism (EUR 222 million), while benefits for airports and ports are estimated at EUR 19 and 10 million respectively.

A relatively high benefit-cost ratio is also expected in the Smart Public Services cluster, where an investment of EUR 10 million can generate 3.5 times the benefit.

The highest ratio of benefits and costs from investing in 5G infrastructure in the Smart Public Services cluster can be expected in the City of Zagreb, where this ratio is as high as 7.7, followed by Osijek-Baranja and Vukovar-Srijem County (4.5 and 3.8 respectively). The lowest ratio is expected in Lika-Senj County.

The potential for benefits from the 5G network can be even more significant, especially in the Smart Manufacturing and Logistics clusters in the case of a more successful transformation of industry and other enterprises, and in the Smart Public Services cluster if public institutions adapt activities to new possibilities to a greater extent.

A benefit-cost ratio of 2.7 can be expected in the Smart Urban cluster, where infrastructure investment costs are estimated at EUR 65 million and use-related benefits of urban hotspot networks and opportunities to optimize certain urban systems to EUR 178 million. The largest net benefits in GDP terms from investments in 5G in this cluster are expected in the City of Zagreb and they amount to 0.3 percent of GDP.

A benefit-cost ratio of investing in 5G infrastructure varies significantly across counties due to differences in their economic structure that determines the potential for benefits and due to differences in their demographic and geographical characteristics. The ratios of benefits and costs that are higher than the national average (3.0) are recorded by the City of Zagreb (4.5), Bjelovar-Bilogora (4.2), Koprivnica-Križevci (4.1), Međimurje (3.8), Osijek-Baranja (3.7), Istria (3.4),

Vukovar-Srijem (3.2), and Virovitica-Podravina counties (3.1). The lowest benefit-cost ratios are recorded in Lika-Senj (1.7), Krapina-Zagorje, and Primorje-Gorski Kotar counties (2.0). The only county in Croatia where the benefit-cost ratio of 5G infrastructure is higher than the European average is the City of Zagreb.

Bjelovar-Bilogora County has the largest net benefit from investing in 5G infrastructure, expressed as a percentage of GDP (3.8 percent of GDP), followed by Koprivnica-Križevci, Istria and Dubrovnik-Neretva with 3.6, 2.8, and 2.7 percent of GDP respectively. Primorje-Gorski Kotar County (1.1 percent of GDP) and the City of Zagreb have the smallest net benefit from investing in 5G. Although Zagreb has a high benefit-cost ratio it also has a high achieved level of total GDP, which makes its net benefit from the 5G network measured by GDP relatively lower.

The highest net benefit from investing in 5G infrastructure per capita per year is in Istria County (EUR 27.8), followed by Dubrovnik-Neretva County (EUR 23.3), the Bjelovar-Bilogora County (EUR 22.5), and Koprivnica-Križevci County (22 EUR). These four counties are also the only counties with net benefit per capita higher than the European average of EUR 21. Krapina-Zagorje (EUR 7.3), Šibenik-Knin (EUR 8.7), and Zagreb County (EUR 8.9) have the lowest net benefit per capita per year.

The time dynamics of the spread of the effects of 5G infrastructure development is not uniform. Once the 5G infrastructure is installed and ready for operation, it takes some time for adaptation and industrial transformation, after which there is a rapid growth in the use of infrastructure, until the moment when technologies that use 5G infrastructure are widespread in the economy and everyday life. With the maturity of 5G deployment, there is less and less room for further accelerated growth of benefits, so the curve of expected benefits is characterized by s-shape.

In addition to the analysis of the costs and benefits of investing in 5G infrastructure, an assessment of the impact of increasing mobile speeds to the lower threshold of 5G speeds on the business of entrepreneurs from

individual industries and counties was conducted. Emphasis is placed on entrepreneurs from the manufacturting industry, tourism, ICT, transport, healthcare, and agriculture, because these industries are either use cases in which the greatest transformation of business is expected due to the use of 5G technologies, or it is a use case (tourism) which needs to be included in the analysis due to its exceptional importance for the overall Croatian economy. The aim of the analysis is to assess the potential effect of increasing the speed of user access to the network on the emergence of new companies, export sophistication of companies, their operating costs, their sales revenues, exports, and employment for these industries for all counties in Croatia. The results of the analysis suggest the following conclusions:

Increasing mobile speed to a level attributable to the 5G network has the greatest impact on increasing the share of new businesses in the ICT sector and tourism. In relation to the average of the observed period, the deployment of the 5G network has the potential to increase the share of new business entities in the total population of companies by 25 percent in the City of Zagreb to as much as 250 percent in the case of Brod-Posavina County. In general, stronger positive effects of the deployment of the 5G network on the establishment of new companies are expected in less developed areas and areas away from major urban centers.

The introduction of a 5G network accompanied by an increase in mobile speeds also has statistically significant effects on increasing the technological complexity of export products and services. At speeds that can considered the lower threshold of the 5G network, export sophistication in the transport sector should increase by 5 percent, in ICT 7 percent, in the manufacturing industry 19 percent, while in the agricultural sector it should increase by 25 percent. Virovitica-Podravina, Karlovac, Bjelovar-Bilogora, and Požega-Slavonia counties have the greatest potential for technological compounding of export products due to the deployment of 5G network, while counties with great potential for attracting new companies and increasing the share of new companies will generally record a decrease in technology complexity. In the tourism and healthcare sector, the deployment of 5G favors the emergence of less sophisticated (usually price-competitive) products and services.

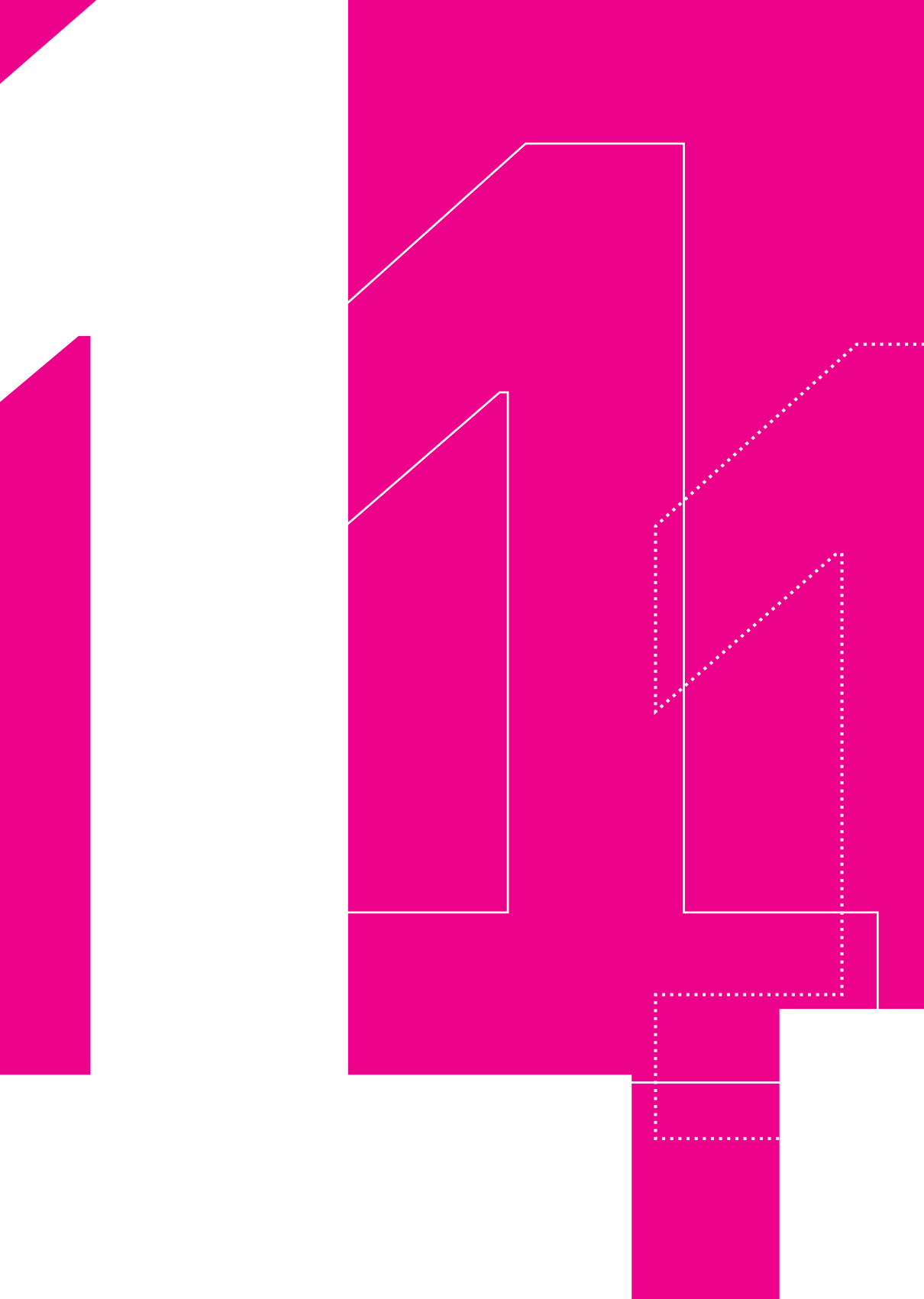
It is expected that the increase in mobile speed as part of the deployment of the 5G network will result in a reduction in operating costs in the ICT, agriculture, and transport sectors, where expected reductions of operating costs share in total revenues range from 20 percent in the ICT and transportation sectors to 30 percent in the agricultural sector. Reduction of operating costs can be expected in all counties except Karlovac, Sisak-Moslavina, Vukovar-Srijem, and Bjelovar-Bilogora. The largest cost reductions are expected in Požega-Slavonia (29 percent), Lika-Senj (25 percent), and Istria County (21 percent).

All sectors expect to increase sales revenue with the deployment of the 5G network. Revenues should thus increase by 20 percent in the manufacturing industry and by 50 percent in tourism and ICT. The City of Zagreb and Zagreb County are in the lead in terms of the expected increase in sales revenue, with the effect in the case of Zagreb being almost twice as high as in all other counties. Revenues in the City of Zagreb should increase by 107 percent due to the deployment of the 5G network. A large increase in revenues is also expected in Primorje-Gorski Kotar (31 percent) and the Split-Dalmatia County (25 percent), i.e., in the counties where the second and third largest Croatian cities are located.

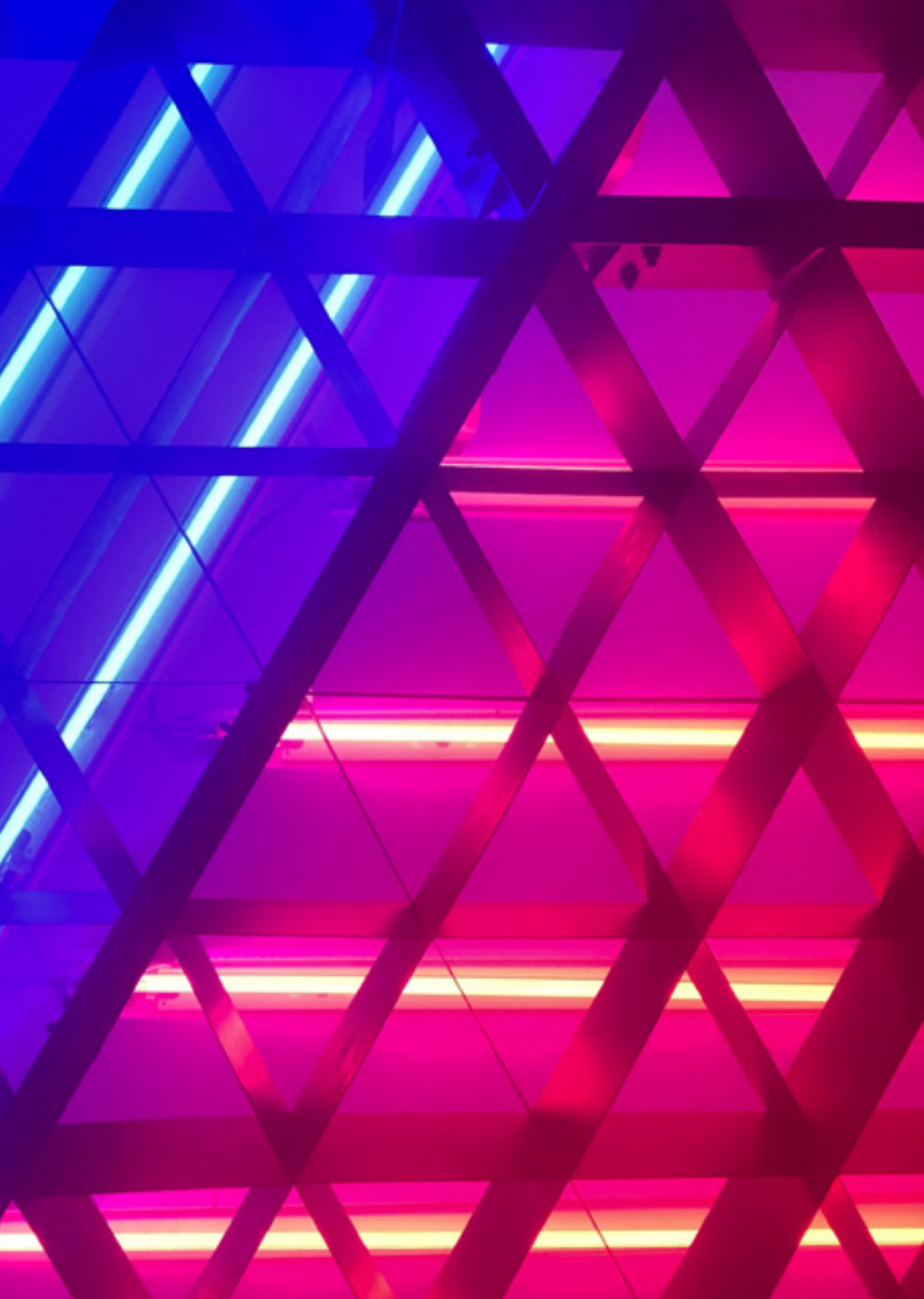
The deployment of the 5G network and the consequent increase in mobile speeds will bring benefits in the form of increased employment in all analyzed sectors. The range of estimated increase in employment ranges from 46 percent in ICT, 43 percent in tourism, to 8 percent in manufacturing industry. At the county level, the highest intensity of the positive effect of increasing speed on employment was recorded in the City of Zagreb, followed by Zagreb, Split-Dalmatia, Primorje-Gorski Kotar and Istria County, where employment growth is estimated at between 16 and 24 percent.

Estimates for the total economy of the Republic of Croatia suggest that the deployment of the 5G network could increase export sophistication by 10 percent, reduce operation costs by 10 percent. It would open the potential for up to three times higher share of new companies in the total population of business entities. These es-

timates are not definitive and can be considered relatively conservative because they are based on data that can only be interpreted as the lower limit of future 5G speeds and because they do not take into account the future impact of mass Internet of Things and mission-critical capabilities which, at higher speeds, represent the basic characteristics of the 5G network.



Introduction



If we analyze the history of the development of human civilization, it is easy to see that new general-purpose technologies such as wheels, printing press and steam engines, electricity, telegraphs, computers, and the internet represented major milestones in lifestyle and business. The discoveries and wide application of these general-purpose technologies, each in the period in which they took place, drastically changed the social and economic structure and processes. They redefined social relations, work processes and rewrote the rules of comparative economic advantage and had positive effects on productivity and physical capital and people's living standards. In this sense, the installation, development, and wide application of mobile digital technologies based on 5G infrastructure can be seen as the next general-purpose technology that will be a catalyst for new changes in lifestyle and business.

After the incubation period ends and mobile digital technologies based on 5G infrastructure enter mass use, we can expect that many economic sectors and the economy as a whole will go through cycles of transformative and sometimes very disruptive changes. Mobile digital technologies have so far progressed from connecting people to sharing and using data on which people depend in both their personal and professional lives. But as digital technologies based on 5G infrastructure become more embedded in devices, machines and processes, wireless connectivity will become the basis of many industries, which will lead to continuous improvement of these industries, a significant increase in their productivity, innovation, and ultimately, to redefining the economic competitiveness of industries and national economies.

The standard features of the 5G network in terms of improved mobile data speeds, mass IoT and mission-critical capabilities mean that the same 5G infrastructure can be applied in many industries and use cases such as autonomous driving, telehealthcare, and automated manufacturing. Over time, the diffusion of mobile technologies based on 5G infrastructure will expand and deepen, and these technologies will become more widely used in industries where their application is currently very limited. This will lead to mobile wireless technologies being able to achieve a very deep and sustainable impact on a wide range of economic activities and industries, and will largely determine the future trajectory of both national economies and global economic processes.

For technologies based on 5G infrastructure to come to life and achieve their pervasive impact on people's lives and the business of industries through various use cases, it is first necessary to develop 5G infrastructure, i.e., to physically install it. Given that the cost of deploying a 5G network is not insignificant, and given that private interest in deploying this infrastructure is largely limited to those areas and uses where such capital investment is commercially viable, it is particularly important to assess the potential future benefits from the development of 5G infrastructure and compare these benefits with the costs of installing 5G infrastructure in order to quantify the economic return on investment in 5G infrastructure, and thus gain a sense of the importance of both private and public investment in 5G infrastructure.

The aim of this study is therefore to assess the future economic benefits of developing 5G infrastructure and compare them with the expected costs of investing in the development of this infrastructure. The second chapter of the study provides a brief overview of the basic characteristics of 5G infrastructure. The third chapter describes the basic expected benefits that individual industries and use cases will have from the development of this infrastructure and digital mobile technologies that will be based on them.

The fourth chapter presents an analysis of the results of the economic effects of the development of 5G infrastructure in the Republic of Croatia. The analysis is divided into two parts. In the first part of the chapter, we analyze the effects of increasing mobile speeds, which is only one of the three main characteristics of the 5G network, on the business of entrepreneurs from individual industries and counties. We focus on entrepreneurs from the manufacturing industry, tourism, ICT, transport, healthcare, and agriculture because these industries are either use cases in which the greatest transformation of business is expected due to the use of 5G technologies, or it is a use case (tourism) which needs to be included in the analysis due to its exceptional importance for the overall Croatian economy. In this part of the analysis, we assess the potential effect of increasing the speed of user access to the network on the emergence of new businesses, export sophistication of companies, their operating costs, their sales revenues, exports, and employment for these industries for all counties in Croatia.

In the second part of the chapter, we present the results of estimating the costs of 5G network development for four economic clusters: Smart Manufacturing, Smart Rural, Smart Urban, and Smart Public Services for all counties and we compare them with the estimated benefits of developing a 5G network. The aim of this analysis is to determine the overall cost-effectiveness and economic justification of investing in 5G infrastructure development and to determine which clusters and use cases have the greatest economic potential and where the greatest constraints are to achieve greater benefits from 5G development. In the second part of the fourth chapter, we present a comparison of the estimated benefits from the development of the 5G network for the Republic of Croatia in relation to other EU member states, to assess the position of our country within the broader economic community. It should be noted that both analyzes described in Chapter 4 were conducted using rather conservative initial assumptions, which means that estimates of the benefits obtained represent the lower limit of the expected future economic benefits from the development of the 5G network.

In the last chapter, we present the basic results of the analysis and propose guidelines for future public policies related to the development of 5G infrastructure and the application of 5G technologies in life and business.

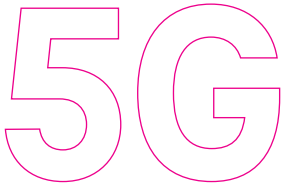
2

Basic determinants of 5G

2.1. Technical characteristics of 5G

What is 5G?

5G is the fifth generation of mobile networks that represents a new standard in global mobile networks. 5G is based on the OFDM (Orthogonal frequency-division multiplexing) method that modulates the digital signal over several different channels to reduce interference. The 5G network uses NR air interface with OFDM principles, and broadband technology such as sub-6 GHz and mm-wave. The 5G network follows 1G, 2G, 3G, and 4G networks. According to GSA data from October 2021, 469 operators in 140 countries/territories are investing in 5G, including trials, licenses, planning, network implementation, and activation.



Higher efficiency and energy saving 5G consumes less energy on devices. Higher network capacity will allow IoT with a much larger number of devices – 5G increases the battery life of IoT devices by 10 times.

5G is an innovation platform
5G is a game-changer for industry and society. 5G has the potential to enable billions of connected devices to share information in real time, transforming the way people live and do business.

Greater reliability
Users should have a maximum of 10 milliseconds between the time of the activity and the network response (so-called latency), which is significantly less than 30 – 40 milliseconds characteristic of 4G.

Speed growth
5G will increase the download speed to 10 GB per second (4G is 1 GB per second).

5G Enables Industry 4.0
The ability to connect quickly and securely is key to developing a new generation of apps and services. 5G provides the basis for the application of the concepts of smart factories, smart education, smart city, smart vehicles.

Improved manufacturing processes depend to a large extent on the high-speed instantaneous data transmission.

Historical development of 1G – 2G – 3G – 4G – 5G

Every decade, new network technology (abbreviated G) emerges that represents a dramatic advance in terms of improved user experience, reduced latency, and broader mobile broadband access than the previous one (Table 1). Knowledge of the historical development of mobile communications networks is an important prerequisite for understanding the importance and impact of the 5G network on business and life in general.

Table 1 **Historical development of mobile communication networks**

Network	1G	2G	3G	4G	5G
Technology	Connects people			Connects people and devices	Connects the world
Launched	1979	1991	2002	2009	2019
Latency			300ms	30 – 40ms	<10ms
Speeds	0.0024 Mbit/s	0.064 Mbit/s	42 Mbit/s	1,000 Mbit/s	10,000 Mbit/s
Reach			Millions of devices	Billions od devices	Trillions of devices

Source: Accenture (2021); IHS (2019); Siemens.

The first generation 1G is associated with the emergence of the first commercial mobile network in Tokyo – Nippon Telegraph and Telephone (NTT). By 1984, NTT had covered all of Japan with a 1G network. The 1G network came down to analog voice transmission and had several shortcomings such as poor sound quality, lack of roaming support between different operators, calls were not encrypted and there was incompatibility between different systems.

The first commercial 2G network was launched in Finland in 1991. It was launched in accordance with the GSM standard. The 2G network has enabled digital voice transmission, SMS, and MMS messaging, and improved security due to digital encryption capabilities. Despite the low speeds, the 2G network for the first time enabled a change in the business environment and allowed a small contribution to the industry itself, which was lacking in the case of the 1G network.

With the development of the 3G network, the internet was transferred from the desktop to our phones. The first commercial 3G network was

launched in South Korea in 2002. Compared to 2G, the new generation 3G has increased data transmission capability by 4 times. The 3G enabled new services such as video conferencing, video streaming, and voice over IP.

The first commercial 4G network was launched in Sweden and Norway in 2009 in accordance with the Long Term Evolution (LTE) standard. The 4G network has brought not only the internet, but also music and video content to mobile phones. 4G has offered high-speed mobile internet access which smoothed the way for video gaming, HD video, and HQ video conferencing services. The specificity of the development of the 4G network was that its introduction implied the design of mobile devices that support such technology. This is a standard that is currently at the forefront in most parts of the world.

The first commercial 5G network was launched in South Korea in 2019. It is a network that is faster and more reliable than all previous generations. In addition to significantly faster internet, it also offers support for mass Internet of Things - IoT and mission-critical communication. It is an innovation platform that allows data to be processed closer to the location where it is used. 5G network enables significantly faster internet access compared to 4G, it is characterized by higher capacity and lower latency, as well as greater reliability and security. The 4G network is mainly designed for mobile phones. On the other hand, the 5G network is allows more flexible use and can function as multiple separate networks at the same time (network slicing).

Every advancement in mobile networks has brought change for the better to users, but what about the industry? Apart from the 1G generation where there was no contribution to the industry, all other generations brought changes to it. Text messages enabled by the 2G network made it easier to remotely control machines. The 3G network provided semi-live telecontrol and remote access to machines, while 4G provided full and live remote access. While the change in the others was incremental, the change from 4G to 5G is significant. Accordingly, 5G has played a significant role in the fourth industrial revolution as it enhances mobile broadband access, enables higher speeds, reduced latency, and greater communication reliability. The ability to connect quickly and securely is key to developing a new generation of apps and services, and 5G

provides the basis for the concepts of smart factories, smart education, smart cities, and smart vehicles. Improved manufacturing processes depend to a large extent on the high-speed instantaneous data transmission and the 5G network that enables this is the backbone of Industry 4.0. Digitalization of manufacturing has the potential to introduce significant improvements in industrial processes based on smart and autonomous systems that can analyze large amounts of data in a short time, and adequate software support that enables machine learning (ML) and appropriate response in accordance processed data. A key factor in the fourth industrial revolution is the ability to communicate well between computers and the ability to transfer some activities to machines without the need for people to participate in such activities. Such a revolutionary change involves a combination of cyber physical systems, IoT, and the Internet system (IoS). IHS (2019) points out that the 5G network will be a platform that will encourage the creation of new business models and the transformation of industries and economies around the world.

2.2. Three pilars of 5G

Three pillars of 5G are:

- Enhanced Mobile Broadband eMBB – a simple goal of the 5G network to ensure optimal data transfer speeds to offer a high level of service everywhere (households, office buildings, shopping malls) with improved capacity to connect a significantly larger number of devices. This progress is important because it optimizes the network for industrial applications, especially through the use of live video surveillance, augmented reality (AR), and virtual reality (VR). The eMBB use cases represent improvement of existing services and will have a significant effect on economic activity. Still, the effect of MIoT and MSC use cases has more pronounced net economic effect.

- Mass IoT (MIoT) - 5G designs the entire system to support large machine-to-machine and low-power IoT networks in licensed and spectra. Mass IoT will enable apps in asset tracking, smart agriculture, smart homes, and smart cities (IHS, 2019).

Mission-critical services (MSC) – The architecture and features of the 5G network make it possible to provide appropriate support to apps which require minimal network data processing latency. For example, for autonomous vehicles, drones, industrial automation, telemedicine (remote patient monitoring), and smart grids, data processing latency must be kept to a minimum. Telemedicine based on the 5G network will enable devices that monitor the patient's condition in their homes to send a continuous sequence of data to the service provider, making it possible to react immediately if the patient's condition deteriorates. These capabilities are considered key to supporting new market opportunities by enabling highly reliable 5G connections, ultra-low latencies, and strong security and availability.

There are two basic requirements for 5G networks – Massive Machine Type Communications, and Ultra Reliable Low Latency Communications. We have a mass connection of IoT devices ahead of us, which is only possible with the help of the 5G network. Specific applications require device communication with extremely short latency, for example, robotics in industrial plants or surgery, etc. It is the 5G network that is the foundation for Industry 4.0, that is, the communication of devices and machines, i.e., things.

2.3. Spectrum requirements

There is no single spectrum that can meet all the requirements of 5G and allow the realization of all the possibilities this network offers. IHS (2019) lists different spectrum levels (low, medium, and broad band), each of which has physical characteristics that best suit different types of 5G use case implementations. Low band (700 MHz) corresponds to the coverage of larger areas, including outdoor areas in urban, sub-urban, and rural areas. The middle band (3.6 GHz) is suitable for use in urban areas and has a good combination of coverage and capacity advantages. Most commercial 5G networks rely on spectrum in the 3.5 – 4.2 GHz band, which is a signal to regulators to allocate a maximum of 5G spectrum

in this band (GSMA, 2021). The high band (26 GHz) is a millimeter wave (mmWave) for multi-giga bits of data, ultra-low latency and much more capacity (IHS, 2019). The GSMA (2021) states that more spectrum will be needed in the long run to maintain the quality of services provided by the 5G network and to meet growing demand, which implies a combination of different frequency bands such as 700 MHz, 2.1 GHz, 3.6 GHz, 6 GHz, 26 GHz.

The European Union prioritizes the 700 MHz band for the low band, while many countries around the world support the 600 MHz spectrum, including the United States (GSMA, 2021). 5G can use licensed and unlicensed spectrum, and spectrum sharing with 4G technology is possible (Dynamic Spectrum Sharing).

Also, the GSMA (2021) suggests that regulators may allow operators to share spectrum and network voluntarily to support the development of ultra-fast 5G services, more efficient use of spectrum, and increase the benefits of network sharing. In addition, it is proposed that governments adopt national spectrum allocation policies that encourage long-term investment in 5G networks, relating to:

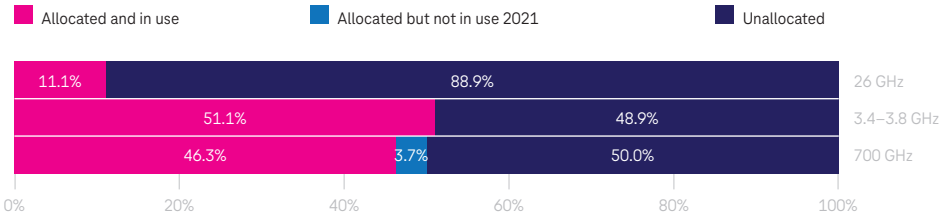
- support for exclusive, long-term licenses covering wider areas with predictable license renewal criteria
- adoption of national broadband plans that include 5G
- publication of a 5G spectrum map
- ensuring that all mobile licenses are technology-neutral to accelerate the widespread use of 5G and encourage improvements in spectrum efficiency.

Most regulators allocate spectrum in conventional ways (national auctions, exclusive 5G licenses), while some regulators have opted to set aside part of the spectrum in priority 5G bands for local companies to build their private 5G networks (GSMA, 2021).

The European Commission has set 700 MHz, 3.6 GHz, and 26 GHz as the basic frequency bands for the implementation of 5G technology. Gigabit 5G in this phase will be based on three frequency bands: 700 MHz allows the prevalence of broadband internet access, 3.6 GHz allows gigabit speeds and mobility, and 26 GHz allows high capacity and higher, giga-

bit speeds for stationary applications. In 2021, 51.1 percent of the 3.4-3.8 GHz frequency band was allocated and used in the EU-27 (Figure 1).

Figure 1 **5G spectrum in EU-27 in 2021**



Source: 5G Scoreboard, EU-27 Scoreboard (January 2021); 5G Observatory

How to get the spectrum in Croatia?

The 5G network works in such a way that a base station transmits a radio frequency signal and communicates with a mobile device, just like previous generations of mobile networks. In Croatia, 700 MHz, 3.6 GHz, and 26 GHz frequency bands are mainly used for 5G technology. It is possible to implement 5G in the frequency bands currently used to provide services via previous generations of mobile networks (2G, 3G, and 4G), which is already in use in the frequency bands used for 4G technology, where simultaneous availability of 5G technology using dynamic spectrum sharing is enabled. On October 29, 2020, HT introduced the first commercial 5G network in Croatia through the DSS. Additional new frequency bands will be allocated in the future.

During July and August 2021, the Croatian Regulatory Authority for Network Industries – HAKOM conducted a public auction for the allocation of radio frequency bands on 700 MHz, 3.6 GHz and 26 GHz at national level and 3.6 GHz at regional (county) level. At the national level, the spectrum was allocated to A1 Hrvatska, Hrvatski Telekom and Telemach Hrvatska, which started providing commercial services via the 5G network. EOLO also received a license to use the 26 GHz band.

Licenses for the use of radio frequency spectrum have been granted for a period of 15 years, with the possibility of extension for 5 years. HAKOM plans to conduct 2022 a new public auction procedure for the allocation of rights of use for the frequency bands 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, and 2600 MHz, as existing licenses expire in 2024. Depending on the development of technology, HAKOM will also consider the allocation of new radio frequency bands.

2.4. 5G Strategy Papers of the European Union and the Republic of Croatia

How is the EU shaping and implementing the 5G vision?

EU 5G strategy papers

2013	The European Commission (EC) has recognized the 5G network as a generator of opportunities for society and business and has begun to encourage public-private partnerships to accelerate R&D in 5G technology. Through the Horizon 2020 program alone more than EUR 700 million were provided to support this activity.
2016	The 5G Action Plan was adopted.
	Early launch of 5G network in selected areas – by 2018.
	Adoption of the European Electronic Communication Code (EECC) which encourages investments – by 2018.
	Commercial launch of 5G services in at least one city in each member state - by 2020.
	5G in all urban areas and along the main transport routes – by 2025.
	European 5G Observatory – Monitors the progress of the 5G Action Plan.
	5G spectrum – a plan to assign a combination of 5G spectra of different characteristics.
2016	EU Gigabit Society (EGS) – the goal of uninterrupted 5G network coverage for all urban areas and major transport routes by 2025.
2021	EU Digital Decade.
	Presents a vision of digital transformation in the EU by 2030.
	The backbone of the digital compass consists of 4 key areas: ICT skills, business transformation, secure and sustainable infrastructure and digitalization of public services.
	5G is the key to success – the goal is to cover all populated areas with the 5G network by 2030.
2021	Recovery and Resilience Facility (RRF) – 5G infrastructure is recognized as a key area for investment in green and digital recovery - a significant part of the EUR 150 billion budget should be used to invest in 5G network infrastructure.
	Complementary with the Connecting Europe Facility and the Digital Europe program.

In accordance with the EU 5G Action Plan, on January 23, 2020, the Government selected Osijek as the first Croatian 5G city where the plan is to achieve 5G signal coverage and commercial provision of services by the

end of 2020. By decision of the Ministry of Maritime Affairs, Transport and Infrastructure in October the Commission for the Drafting of the Strategy for the Transition of Digital Terrestrial Television to the DVB-T2 System and the Allocation of the 700 MHz Frequency Band was established in 2015. In 2017, HAKOM established a 5G working group to identify open issues and challenges related to the 5G mobile communications network to deploy 5G technologies in the Republic of Croatia as quickly and easily as possible.

The National Plan for the Development of Broadband Access in the Republic of Croatia 2021 to 2027 is in force in the Republic of Croatia. The Plan recognizes all the obstacles due to which Croatia lags in the development of broadband access. The third and fourth objectives of the Plan relate to 5G – Deployment of 5G networks in urban areas and along major land transport routes and deployment of 5G networks in rural areas. One of the measures of this document refers to encouraging the deployment of 5G networks, within which the plan is to provide the necessary radio frequency spectrum for the introduction of 5G networks. Additional activity under this measure relates to the implementation of spectrum allocation procedures for 5G networks, which will stimulate operators' investments in development and increase the availability of 5G networks by the end of 2021 in accordance with the third and fourth objectives of the National Plan. In accordance with the measure, following the public auction, on August 12, 2021, HAKOM adopted decisions on the allocation of radio frequency bands at 700 MHz, 3.6 GHz, and 26 GHz at the national level and 3.6 GHz at the regional (county) level. Licenses for the use of RF spectrum are granted for a 15-year period (except in the case of licenses issued at the regional level in Međimurje and Varaždin counties, where there are already licenses issued in the spectrum valid until 2023 – new 13-year licenses were issued for these areas), with the possibility of extension for the next 5 years.

The latest report on the DESI index for Croatia for 2020 states that the National Framework Program for the Development of Broadband Access Infrastructure, co-financed by the EU, plans to enable 240,000 households to be covered by the fiber-optic network by the end of 2023. It also states a plan to supplement private investment with public funding and to cover another 210,000 households and businesses with a fiber-optic

network. HAKOM recognizes an investment gap of EUR 778 million for 740,000 households, mostly in rural areas, to achieve full coverage by a very large capacity network (European Commission, 2021).

The Croatian Recovery and Resilience Plan envisages an investment of EUR 106 million to improve connectivity in line with the EU's 2025 Gigabit Connectivity target by investing in services at speeds of at least 100 Mbit/s for 100,000 Croatian households in 20 projects in 20 local governments and services with speeds of at least 1 Gbit for all major socio-economic drivers such as schools, universities, research centers, transport hubs, hospitals, government agencies, and businesses. Approximately EUR 20 million is planned to be invested in the development of passive electronic communications infrastructure for access to very high capacity and 5G networks in rural and sparsely populated areas where there are no market conditions that would attract private investment and in 5G network coverage in urban area and major land transport routes (5G corridors) (European Commission, 2021).

2.5. 5G in Croatia

The leading domestic operator Hrvatski Telekom (HT) is a leader in the development of 5G network and services and investment in 5G network. HT with 600 5G base stations on 2.1 GHz DSS and 150 base stations on 3.6 GHz, with a 5G network that at the end of 2021 covered 76 cities and towns and two million inhabitants. HT is the first service provider to launch a commercial 5G network on October 29, 2020, in Croatia, when it covered six cities with a 5G network – Zagreb, Split, Rijeka, Osijek, Samobor, and Sveta Nedelja. HT has made 5G network available in 17 Croatian cities by the end of 2020. The commercial 5G network in 2020 was based on dynamic spectrum sharing technology – DSS. By the end of 2020, 5G DSS technology was implemented on 323 base stations.

At the public auction held in August 2021, HT invested HRK 130 million and won the most radio frequency spectrum – in the 700 MHz frequency band a 2×10 MHz block was allocated, in the 3.6 GHz frequency band 12 10 MHz blocks (total 120 MHz), and in the 26 GHz frequency band 2

blocks of 200 MHz (400 MHz in total). HT retains the position of the leading operator and investor in the 5G network with the new radio frequencies. HT also undertook to cover certain uninhabited or sparsely populated areas and to build networks in the dynamics prescribed by HAKOM.

HT's plans include the use of 5G technology based fixed wireless access (FWA) on mobile network. This approach is important for semi urban and rural areas where optical infrastructure is not available and there is a need for high-speed Internet.

5G campus networks

Future investments will relate to private 5G business networks users of the so-called campus networks that provide low latency, dedicated bandwidth and allow connectivity of machines and are polygons for revolution in business processes development and solutions based on sensors, automation, robotics and application of artificial intelligence. In December 2020, HT set up a test 5G campus network at FER.

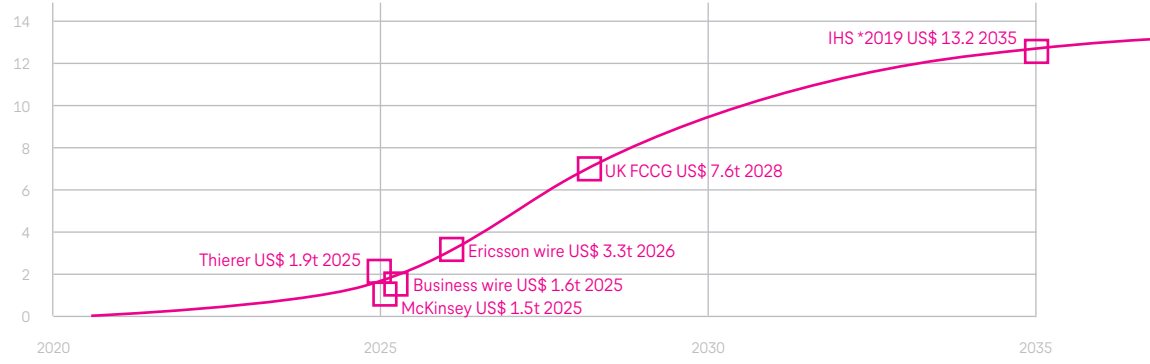
5G clusters and use cases

Building a 5G network creates the preconditions for industry revolution since such technology is necessary for the possibility of digital transformation of the economy and application of IoT and other modern technologies. One of the first comprehensive studies that identify key future socio-economic benefits of introducing 5G networks for the EU economy is presented in the European Commission (2017). Estimates in this study are based on the contribution of more than 150 experts and the results of previous research. Different scenarios were considered, and the authors concluded that the presented estimates can be considered conservative. The effects of the 5G network are limited to four areas: vehicles, health, transport, and utilities. The total cost of introducing 5G in the EU is estimated at EUR 56.6 billion. The cost estimate is based on an insight into the costs of introducing earlier 2G, 3G, and 4G technologies, and it was noticed that each subsequent generation requires a higher amount of unit investments compared to the previous one. In total, it is estimated that the use of 5G networks can generate EUR 113.1 billion in economic benefits annually, which can be divided into primary (EUR 62.5 billion) and secondary benefits (EUR 50.6 billion). Primary economic benefits include direct benefits producers of goods and services in the above four verticals have, with the greatest impact expected for car manufacturing (EUR 42.2 billion). Slightly less than two-thirds of the benefits are expected in the business sector (63 percent), while the rest

relates to the benefits accruing to consumers and society. Secondary benefits are divided into four blocks: workplace, smart city, smart house, and rural areas, and the largest amount of benefits would be realized in the workplace area (30.6 out of a total of EUR 50.6 billion) where IoT technology and rapid access to a wide range of information enable significant productivity growth.

Other relevant estimates of the cumulative economic effects of 5G network development are shown in Figure 2.

Figure 2 **Cumulative economic effects of building a 5G network globally, in trillions of USD**



Source: Taken from Tech4i2 (2019), and WEF (2020).

Analysys Mason (2020) recognizes 5G as an innovation platform that can support a range of innovations in a variety of markets and industry sectors. This study groups the use cases into 4 clusters – Smart Manufacturing and Logistics, Smart Rural, Smart Urban, and Smart Public Services. The research analyzes societal, environmental, and economic benefits at the level of individual use cases, i.e., clusters, and quantifies estimates of economic benefits.

Analysys Mason (2020) concludes that the development of a 5G network in Europe in terms of net present value can bring EUR 210 billion in benefits at a cost of around EUR 46 billion (corresponding to the benefit-cost ratio of 4.5). The largest absolute net benefit of EUR 70 billion is projected for the Smart Manufacturing cluster, followed by the Smart Rural with a net benefit of EUR 55 billion. The effects in the Smart Urban and Smart Public Services clusters in absolute terms are relatively low,

but the expected benefit per unit of investment is higher compared to Agriculture and Industry clusters. Table 2 gives an overview of the costs and benefits associated with the potential of an open innovation platform that can be realized by exploiting the 5G network.

An estimate of costs and benefits is also available for the Croatian economy, and it is expected that in the period up to 2035 the total benefit reduced to net present value could amount to EUR 658 million, or an average of EUR 11 per capita per year.

Table 2 **Overview of the benefits at the level of the European economy (EU, UK, Switzerland, and Norway) related to the 5G open innovation platform**

Cluster	Slučajevi upotrebe	Benefits			
		Economic (cost/benefit)		Social	Environmental
		Billion EUR	Ratio		
Smart Production and Logistics	Smart factories	70/12	6	Increase security; Workers with technological skills	Live surveillance sees a reduction in energy and material consumption; Reduced need to replace equipment
	Mining	14/9	2		Better air quality
	Ports	2/0	7		Reduction in CO_2 emissions
	Airports	5/1	8	Increasing security	Crowd reduction
	Transport and logistics	--			Just-in-time supply chains
	Energy and utility	--		Growth in desirable behavior	Improving energy management
	Cluster total	90/21	4		
Smart Rural	FWA access in rural areas	28/10	3	Growth of social inclusion, decrease digital divisions	Shorter trips
	Agriculture	45/8	5	Rural sustainibility	Efficiency growth; Less need for pastures for livestock
	Cluster total	73/18	4		
Smart Urban	Development	31/3	9	Increasing security	Improving energy use; green development
	Urban growth hotspots	2/0	10	Increasing prosperity	Reduced emissions; Smart buildings; More efficient transport
	Stadiums	--		Better experience; Additional content	Support for green initiatives at stadiums
	Smart cars	--		Increased security; Driving and travel optimization	Growth in energy efficiency and reduced harmful gas emissions
	Cluster total	33/4	8		
Smart Public Administration	Health care	--		Reliable remote consultation and triage; Better care and growth of social inclusion	Shorter trips, More preventive care, with less pressure on hospitals
	Public buildings	12/1	9	Better use of energy/less waste; collaboration	Shorter trips
	Education			Facilitated access to education (remote learning) and access to experts	Green schools
	Tourism			Virtual sightseeing; Better experience; Education	Benefits from the protection of cultural property
Cluster total		12/2	5		
Total effects of 5G		208/46	4.5		

Source: Analysys Mason (2020).

CASE STUDY

Dubrovnik

A new generation network for a resilient city

Thanks to the 5G network, the City of Dubrovnik will offer its citizens and visitors a much higher quality service in traffic, education, health, mobility, transparency and more, building long-term sustainability and resilience to technological and communication achievements.

Basic information

Adopting the Smart City Strategy in July 2015, Dubrovnik began a journey towards the future on which a number of notable results have been achieved so far. Among them is the recognition for the best city in the Smart City category in 2019, which Dubrovnik has earned with numerous projects based on the strategic application of state-of-the-art technological solutions aimed at increasing the quality of life for 42,000 citizens and providing the best destination experience for many visitors.

Projects

The City of Dubrovnik was among the first to recognize the value of new technologies and opportunities and, thanks to previous investments and projects, is ready to experience the benefits that 5G network can bring to citizens and businesses that will provide a faster and safer framework for further development.

In the last seven years, a number of solutions have been implemented in Dubrovnik as part of the infrastructure of the smart city, and some of them are globally recognizable. Dubrovnik was the first in the world to implement the largest smart parking project on the NBIoT network. More than 1,900 parking sensors have been installed across the city, covering the entire city parking space.

The port of Dubrovnik, schools and kindergartens, are equipped with sensors to measure air quality, and thanks to EU funds, and ingenious shar-

ing of infrastructure resources of all its affiliated companies, the city has established a free city Wi-Fi network. Equipment for the establishment of a traffic congestion zone has been implemented, as well as numerous modules for the establishment of a central city information system. The first hybrid center of technological support was given to e-schools, and the city administration is more transparent because citizens have access to all accounts and expenses of the city via an online platform. The VOX POPULI system has also been implemented, which is the first in Croatia to enable citizens through a digital platform to actively participate in city management through participatory budgeting.

The island of Lokrum has received fiber optic infrastructure and sensors that measure air quality, sea quality, and environmental conditions and detect smoke for the purpose of early fire detection.

Future

The new 5G network will expand development opportunities with existing projects, but also with those that will become part of the unique Dubrovnik story. It will enable the integration of IoT, i.e., urban sensor infrastructure (IoT) into the everyday life of citizens and models of city management, making it the technological basis for new development. Citizens and the city administration will have real time access to numerous data and information from the environment thanks to the 5G network, whose latency is extremely low, and the data transfer speed is extremely high.

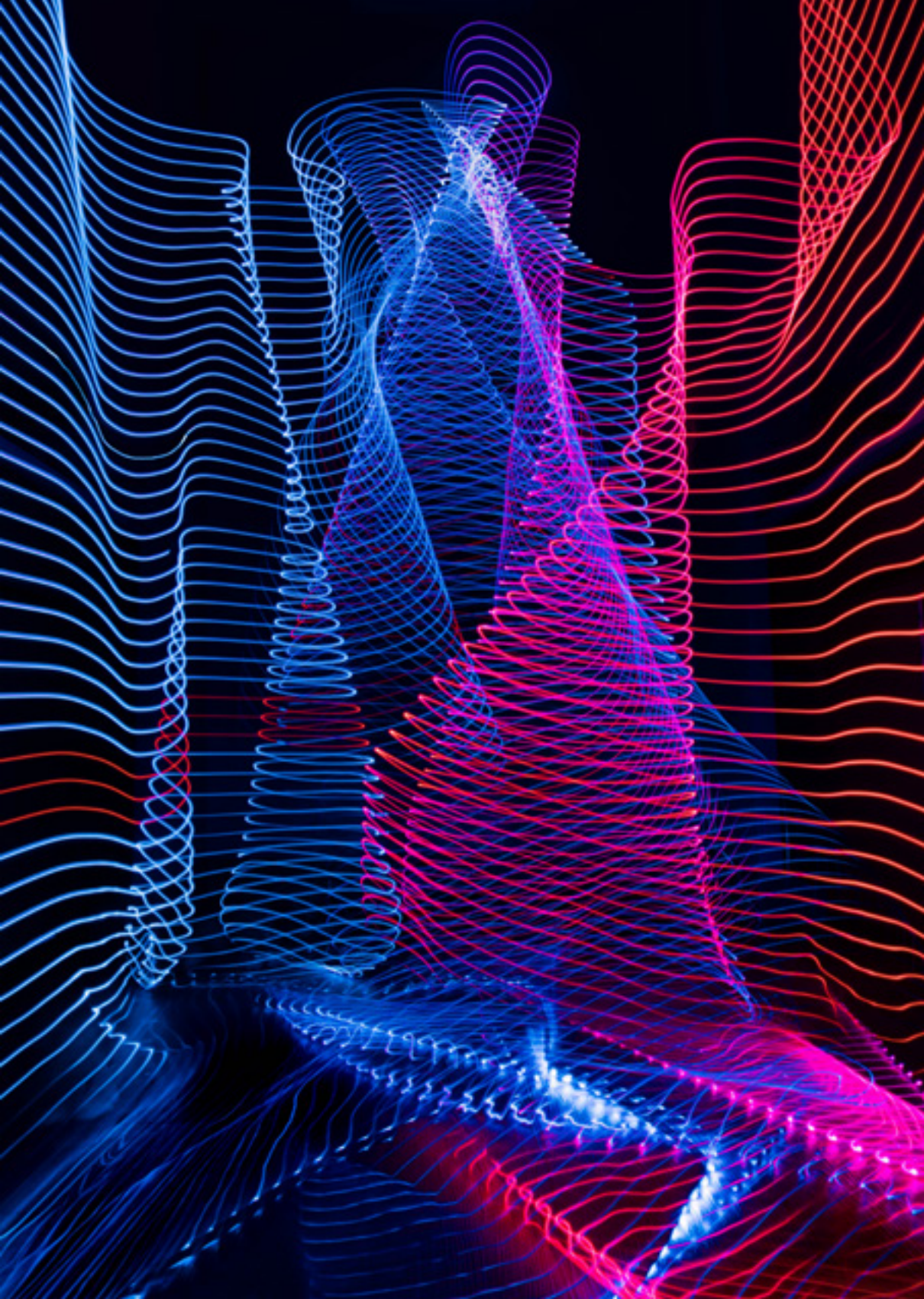
The change is seen in the smart parking service. The change in the status of the parking space from free to occupied on the mobile app on the 5G network is visible in milliseconds.

"The City of Dubrovnik systematically uses encourages new digital technologies and Smart City concepts in order to increase the quality of life of citizens, but also to ensure the best destination experience for visitors. We are especially focused on maximum openness to citizens and their needs, and participatory budgeting projects and the Open City system clearly demonstrate our commitment to this goal. By implementing the Open City system, we have achieved that citizens are informed in detail about the financial operations of the City, their interactions with the City and administrative bodies have been facilitated, and they have been enabled to participate in management and decision making. The digital transformation of city administration, which we launched in 2017, has increased our efficiency and productivity. Dubrovnik is increasingly establishing itself as a leader in smart destination management, and the echoes of this approach have been recognized by the international professional public."

Mato Franković,
Mayor of Dubrovnik

In order to strengthen its resilience and prompted by the COVID pandemic, the City of Dubrovnik decided to disperse economic activities so far based mainly on tourism and focus on encouraging entrepreneurship and

the development of the IT sector. The new 5G network is a key infrastructural precondition for the economic turnaround of Dubrovnik and an opportunity to develop a new form of sustainable tourism, based on digital nomadism and the City's commitment to becoming the center of digital nomadic tourism in Croatia.



2.6. Assesing the effects on productivity and growth of certain sectors of the economy

The introduction of new technologies will not affect the transformation and increase in productivity of different sectors of the national economy in the same way. While in some sectors a complete transformation of the way production activities and the development of completely new products and technologies can be expected, in others, predominantly traditional service activities, the availability of 5G network will not have such a significant effect. Below, based on the available references, the sectors of the national economy where the effect of the 5G network could be significant are identified.

Manufacturing industry

Smart factories will use 5G technology for various areas, the most common being automation, artificial intelligence, and IoT. 5G technology has the potential to increase economies of scale (large quantities of products are efficiently created by system optimization) and economies of scope (variants within the product and/or between products are adapted using flexible, computer-controlled systems). Increasing productivity will be achieved by relying on flexible computer-controlled systems, and the link between production processes taking place in different locations will be enhanced by the ability to transport production inputs and finished products through coordinated and connected logistics systems. Most studies that assess the economic effects of 5G deployment at the sectoral level expect that the manufacturing industry will derive most of the benefits. In total benefits, the share of the manufacturing industry is expected to be between 19 percent globally (Ericsson, 2017) and 27 percent (IHS, 2017). The availability of 5G technology does not in itself

guarantee an automatic increase in productivity, but the transformation of the manufacturing industry requires significant investments in production and human capacity. Manufacturers who recognize the need in time, but also the opportunity to increase their own competitiveness by transforming production, will also increase market share. According to various surveys, the Croatian manufacturing industry lags behind other EU member states in terms of the current technological level of manufacturing industry, level of investment and innovation, and will probably lag to some extent with the transformation of production processes and achieve below-average benefits from the opportunities provided by 5G technology. However, there have been positive examples of successful production development in technologically advanced sectors in Croatia recently, and time will tell whether such cases are exceptions or whether the number of such ventures will grow in the future.

Information & Communication Technology (ICT)

The ICT sector produces goods and services that are necessary for the digitalization of the manufacturing industry in the future, and the transformation of the industry will certainly contribute to the economic growth of this sector. In addition to the manufacturing of devices and software for modern plants, the development of 5G technology will enable a significant expansion of services for end users. Enhancements to mobile broadband through 5G technology will support high-speed data transfer, enabling HD video delivery, game development, augmented and virtual reality experience. The global augmented reality market is growing at a high rate, and growth will certainly accelerate in the future thanks to 5G technology.

Public services

Higher speeds and capacity of 5G networks will enable the transformation and increase the productivity of certain public services. In the set of public services, one of the biggest advantages of 5G is often the improvement in the waste management system. The application of IoT technology, in addition to sensor-equipped trash cans, enables road

optimization for garbage trucks, prevents cans from being overfilled or half-empty, and generally improves the management of the entire system. The application of the 5G network is also possible in public safety. Instead of risks to the workforce, real-time remote-controlled machines can be used in hazardous conditions, such as demining or firefighting. Super-fast internet connection, advanced software and a built-in data analysis system allow extremely fast response in situations that require an urgent response. An analytical system based on timely information collected via the 5G network can also allow the prediction of location and time, and thus the prevention of the negative effects of natural disasters (floods, typhoons, etc.). Other public services can also improve efficiency. An example of this is a smart public lighting system that can provide optimal levels of lighting, depending on traffic in individual locations, while reducing energy costs and environmental pollution. The DESI index 2020 shows that Croatia is at the very bottom in terms of digital public services (24th place). Croatia lags significantly in terms of the use of e-government, while according to the indicator according to the amount of data pre-filled in online forms of public services is far below the EU average (43 percent, the EU average being 63 percent). It is similar with the availability of digital internet services, whether it is for citizens (60 percent and the EU average is 75 percent) or for businesses (73 percent compared to the EU average of 84 percent).

The ability to transfer large amounts of data immediately can also improve the quality of healthcare services, in the public and private sectors. At an earlier stage, the development of apps intended for the improvement of healthcare services is expected, such as continuous monitoring of patients and determining treatment in accordance with observations of the patient, while at a later stage wider application of remote treatment can be expected. Croatia started investing in the digitalization of healthcare early on using the e-prescription service (currently under 2 percent of all prescriptions are issued in printed form). Croatia and Portugal are the only EU Member States participating in the Digital eHealth Infrastructure (eHDSI) with all four services, and Croatian physicians can receive summaries of patients' medical data from other Member States (European Commission, 2021). The National Recovery and Resilience Plan lists significant investments in telemedicine, with the largest amount earmarked for the digitalization of the National Oncology Net-

work and the National Oncology Database, and investments in e-care, teletransfusion, and robotic surgery are planned.

Wholesale and Retail

The use of augmented and virtual reality apps that will be enabled by the development of the 5G network can significantly improve customer satisfaction and support the development of online and traditional commerce and thus increase traffic. Recently, the growth of online sales has been accelerating, and this trend has further intensified in the conditions of limited human contact due to the COVID-19 crisis. We should expect this trend to continue in the future, with the expansion of options that allow the customer to purchase personalized products. The availability of 5G technology supports the development of various consumer apps. Examples are interactive virtual mirrors through which certain clothes can be tried on, and with adequate software, such an app can suggest to customers other clothing items that match the style, color, and size of the selected item. Virtual reality apps can also be used by retailers to introduce new items to the market, without such items being physically available. Increasing the share of online commerce also changes the cost structure of retailers as the need for space in the retail units themselves decreases, and the requirements for the space in which goods are stored increase.

Finance and Insurance

So far, the financial industry has proven to be a sector that is rapidly introducing new digital technologies into regular operations. Recent examples of such innovations are online and mobile banking, services that were almost unknown until about 10 years ago, and today apps are available to all users. The higher speeds and security provided by the 5G network will certainly contribute to the improvement of financial services in the future.

The new technology will enable the use of a broader set of data, the use of algorithms that can detect potential irregularities, and segment consumers according to specific characteristics. Greater availability of

real-time data on previous transactions of individual service users enables the analysis of their habits and preferences and the creation of specially created services that suit the user. The application of artificial intelligence will enable the development of apps that will provide financial advice to users based on the analysis of data on their financial status and past behavior. Such apps, in addition to the role of a personal banker, would be particularly applicable to users seeking advice on the appropriate type of financial investment, based on their financial status and risk appetite. The application of IoT technology with the support of the 5G network can substantiate the development of payment systems via smartwatches or other devices that users use daily, thus reducing the need to carry money or credit cards. Given the speed of the 5G network, various financial transactions would be conducted momentarily. The availability of information on prices and quantities offered and the speed of transactions are particularly important for trading in stocks and other securities, and brokerage firms are expected to be among the first to introduce this technology into their day-to-day operations. Insurance companies will also be able to better determine the risk of a particular client by expanding the availability of a wider range of timely information. Related to the trends in transport in which the increasing use of various sensors and apps in cars is expected, the availability of the 5G network can also be used to facilitate the determination of the circumstances of traffic accidents, as well as to report damage to vehicles.

Transport and Storage

Authors of various studies see significant potential benefits of the 5G network for entrepreneurs in the transport and storage sector in terms of improving productivity, innovation, and competitiveness. The ability to connect and "communicate" between different means of transport has the potential to transform this sector. The introduction of fully autonomous vehicles would require significant investments not only in the automotive industry but also in telecommunications and satellite infrastructure. It is still uncertain at what pace this process will take place. Even without the widespread use of fully autonomous vehicles, 5G infrastructure can improve the productivity of this sector by supporting the rapid real-time transfer of large amounts of data, providing the abil-

ity to optimize transport routes, reduce traffic congestion, and adverse environmental effects. The use of IoT technology based on the use of 5G network allows real-time tracking of shipments, assets, and persons through the entire logistics chain of added value, from warehousing, and long-distance transport to delivery to end customers. A prerequisite for real-time monitoring of shipments is the installation of sensors on the means of transport and the transport goods. In this way, transport companies, and senders or recipients of goods could see the current location of the shipment, but also read in real time other important characteristics, such as temperature, humidity and weather characteristics that could affect the quality of transported goods. The availability of real-time information also enables better connectivity between transport companies and customer and supplier networks in a way that minimizes the distance that vehicles travel without a load.

Hotels and Restaurants

The opportunities provided by the 5G network can increase efficiency and productivity in the hotel and restaurant sector. The use of virtual and augmented reality technologies supported by the 5G network can contribute to the popularization of tourist destinations. Hotel businesses will be able to reduce costs and increase efficiency through the capabilities provided by large data set analysis. IoT sensors can control various aspects of the activity, from regulating the room temperature to delivering food to the room at the request of the guest. The possibility of analyzing a wider set of data opens the possibility of formulating personalized services tailored to the wishes of users. Hotels can expand the quality and content of the service they provide to guests. New technologies expand the entertainment possibilities for guests with the availability of numerous apps they can control with the phone or voice commands. Higher speeds and the ability to download large files allows the guest to use a variety of TV programs and video content on demand. Guests can also be offered new hotel services, such as virtual rowing machines or various courses that guests can access on request.

CASE STUDY

Faculty of Electrical Engineering and Computing (FER)

Real-time monitoring and analysis of traffic flows on public roads using drones

Faculty of Electrical Engineering and Computing, University of Zagreb, a leading Croatian higher education and research institution in electrical engineering, computing and information and communication technology conduct for Hrvatski Telekom a research project of monitoring and analysis of traffic flows on public roads in real time to enable more accurate and faster information of traffic participants, better planning and management of traffic, reducing congestion, increasing safety, faster response and better preparedness of emergency services.

Fundamental steps

In the first of four phases of the project, a drone with appropriate equipment for flight missions was selected based on the developed method-

ology. This is important because the choice of aircraft directly affects the capabilities and performance of systems whose architecture includes mobile communication infrastructure, application server, databases, software middleware for collection of GUI interface data of the operational and and a control and monitoring center and integration software to integrate the system with the location and emergency call services of the mobile communications network. An important part of the whole proposed system is the transmission of high-quality HD video signals via newer generation mobile networks (4G and 5G).

Guidelines and objectives

Road patrol. If we compare it with the standard forms of road patrol, the drone has numerous advantages in the speed of intervention and ease of access to any type of road that it can monitor even in case of bad weather conditions, even when covered with snow. They can quickly and accurately detect sudden sources of danger and monitor permeability.

Early warning system. Unmanned aerial vehicles with a complete surveillance system enable fast detection of the accident site on the roads, which they can report in almost real-time and transmit information on the assessment of the situation, alert the necessary services, identify the fastest way to reach the accident site given the current road situation.

Traffic control and congestion identification. Each road has its own capacity, i.e., the maximum number of vehicles that in certain conditions can go through in one hour in one or two directions if it is a two-lane and three-land roads. Fast and accurate traffic information and congestion detection are important for various services to plan their activities, but also for all road users to plan their trips.

Mathematical modeling of complex intersections. Although detailed research is being conducted in this area and data are being collected on the flow of vehicles through intersections, the speed and density of traffic, the time vehicles spend at intersections, the spatial distance between two consecutive vehicles in traffic and others, the challenge has not yet been resolved of collecting data on problematic intersections throughout the year, which is enabled by the drone surveillance system. The data is later processed by a simulation tool.

Supervision of traffic violations. According to the Bulletin on Road Safety of the Ministry of the Interior, in 2018 the supervision as many as 722,095 violations, and the largest share, as many as 283,044 cases, is related to exceeding the prescribed speed of vehicles. Vehicle speed is monitored by cameras at fixed locations, so it can be concluded that the actual number of violations is much higher, and unmanned aerial vehicles would enable vehicle speed monitoring at arbitrary locations. Unmanned aerial vehicles can also detect other frequent violations, such as disregarding red lights at traffic lights, overtaking and bypassing improperly, not giving way to pedestrians and others.

Smart City It is an urban area where electronic methods and sensors collect data needed to manage property, resources, and services, and improve operations in the city. The drone road monitoring system can be directly applied in all areas of interest of smart cities, ranging from traffic congestion analysis and checking available parking spaces to detecting road congestion and analyzing public transport congestion or waiting for pedestrians to cross the road to spot traffic accidents and responding to them and monitoring traffic violations.

Integration of 5G modules

In the second and third phase of the project a private 5G mobile network is planned to use, while in the expected project phase 4 the plan is to use a public 5G mobile network to test the developed concepts in real working conditions. Choosing a 5G module for the next generation network was a challenge as commercial modules that support drone connectivity to the 5G mobile radio network are mostly still in development and difficult to obtain on the market.

"The idea is to make an integrated surveillance system consisting of one (or more) drones and a computer system on the ground, which are interconnected via a 5G network. Such a system could receive real-time video from a drone, process it, identify vehicles, and people, and draw conclusions using a variety of machine learning algorithms."

Marko Jurčević, PhD, Associate Professor, Faculty of Electrical Engineering and Computing, University of Zagreb

The drone and ground system station must be equipped with compatible 4G and 5G technology so that the entire system can temporarily store data (video streaming) while switching between 5G and other technologies without data loss due to possible data or downtime.

Economic Effects of 5G Infrastructure Development

3.1. Effects of 5G Infrastructure Development on business undartakings

The differences in the effects that the deployment and improvement of 5G infrastructure can have on the business of entrepreneurs at the sectoral or regional level have not been the subject of significant research so far (Jung and Lopez-Bazo, 2020). Cultural, institutional, regulatory, and developmental differences make some regions more conducive than others to achieving the effects of 5G network installation and the development and application of technologies based on that network. Similarly, cross-sectoral differences in business models, culture, structure, and market orientation of entrepreneurs play an important role in the readiness to accept, implement and take advantage of new technological opportunities such as those provided by the 5G network. However, the academic and professional public have not yet reached agreement on issues such as the effects of the 5G network in less or more developed regions or within certain sectors of the economy. Also, the conclusions of existing research are mainly based on estimates of the effects of 5G network availability, while the effects of increasing the speed of network use are generally not analyzed.

Numerous potential effects of upgraded internet infrastructure on economic growth and productivity have been evaluated in the previous studies. Effects on technological complexity and innovation (Katz and Avila, 2010), business efficiency (Castaldo et al., 2018), attraction of new business entities, especially in knowledge-intensive activities, through the creation of new business opportunities (Mack and Rey, 2014; Ford, 2018) are the most important among the numerous potential effects. By assessing these effects, it is possible to gain insights into market dynamism, export sophistication, or cost competitiveness, which are recognized in the relevant literature as links between improving 5G infrastructure and improving growth and productivity (Katz and Avila, 2010).

This chapter aims to assess the impact of increasing the speed of user access to the network on the emergence of new businesses, export sophistication, operating costs, sales revenue, exports, and employment. The period between 2016 and 2019, during which there was a significant increase in user speeds in the Republic of Croatia, was taken as a reference. The average user speed during the observed period in Croatian cities and municipalities was 60 Mbit/s, while in a number of cities and municipalities the user speeds exceeded the values of 140 and 160 Mbit/s. According to Forbes (2020), user speeds of 60 and more Mbit/s exceed the upper limit of 4G network capabilities.

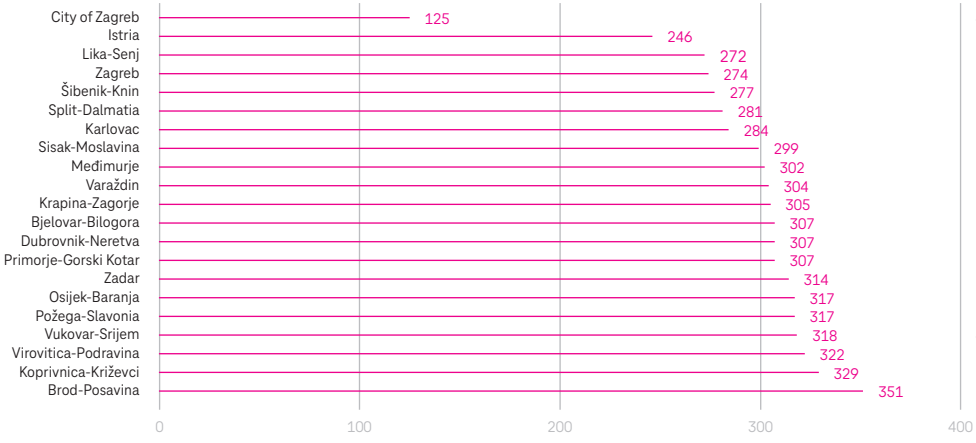
The analysis took as a starting value the average available speed to internet users in the observed period of 60 Mbit/s and estimated the effects at speeds of 100 Mbit/s which include 99 percent of Croatian users and at maximum available user speeds of 140 Mbit/s and 160 Mbit/s. The analyzed effects of network speed do not reflect the full potential of the 5G network, but can be considered its lower limit (Forbes, 2020). Namely, although eMBB (enhanced mobile broadband) and use cases based on it will have a significant impact on economic activity, given the improvement of existing services, the net economic effect of this 5G network pillar will be less intense and transformative from the effect of MIoT and MSC use cases. At the same time, these are the highest available user speeds in Croatia and the estimated results can be considered the lower limit of the potential effects of the 5G network.

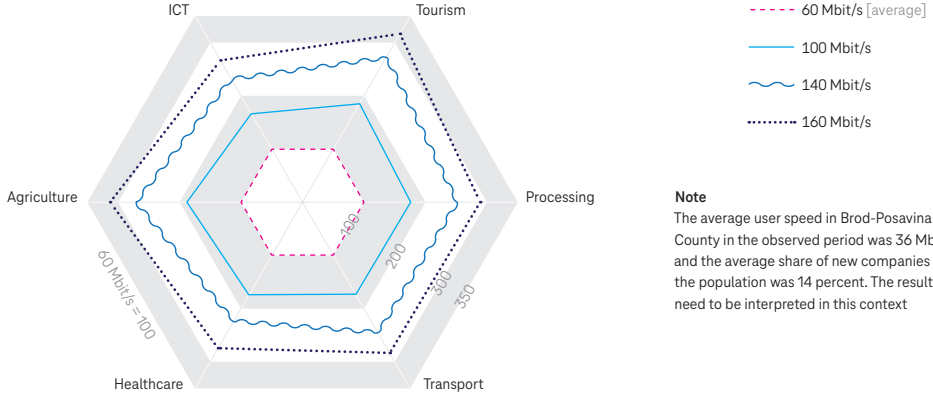
The analysis included all Croatian cities and municipalities, i.e., all active business entities in the Republic of Croatia in the observed period. To allow comparability with estimates carried out for other economies (i.e., Accenture, 2020) and regions, the sectors of manufacturing, agriculture, healthcare, transport, and ICT were selected, to which the tourism sector was added due to its importance for the Croatian economy.

Effects of 5G infrastructure development on businesses – Emergence of new businesses

- For the sake of clarity, the estimated effects at different network speeds are expressed in the form of an index, where the initial value is the average network speed available to Croatian users in the observed period.
- The effect of increasing speed to the levels attributable to 5G on the increase in the share of new business entities in the company's population ranges from 2.7 in the healthcare and ICT sector to 3.2 times in the tourism sector.
- An analysis of the effects by Croatian counties reveals an uneven distribution and much stronger effects in less developed counties. Compared to the average of the observed period, the introduction of the 5G network has the potential to increase the share of new business entities from 1.25 times in the City of Zagreb to 3.5 times in the case of Brod-Posavina County.
- The findings are in line with expectations of stronger positive effects of the deployment of the 5G network on less developed areas and those away from major urban centers.

Share of new business entities (index)



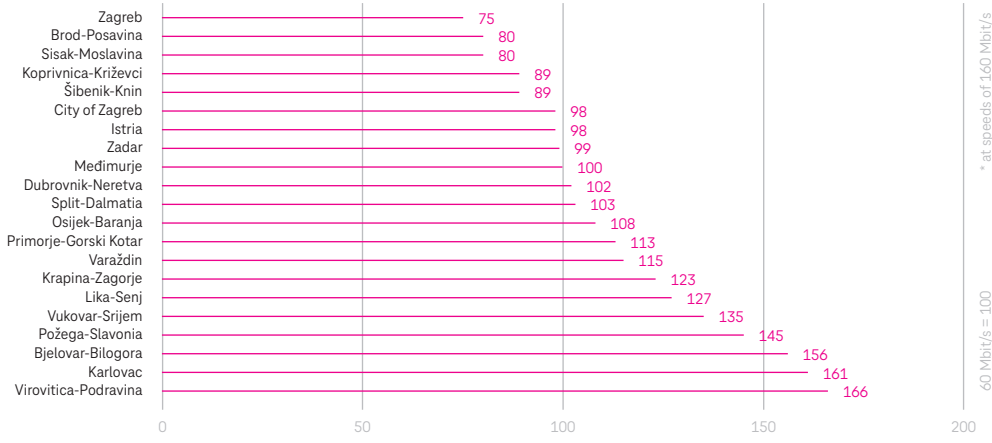


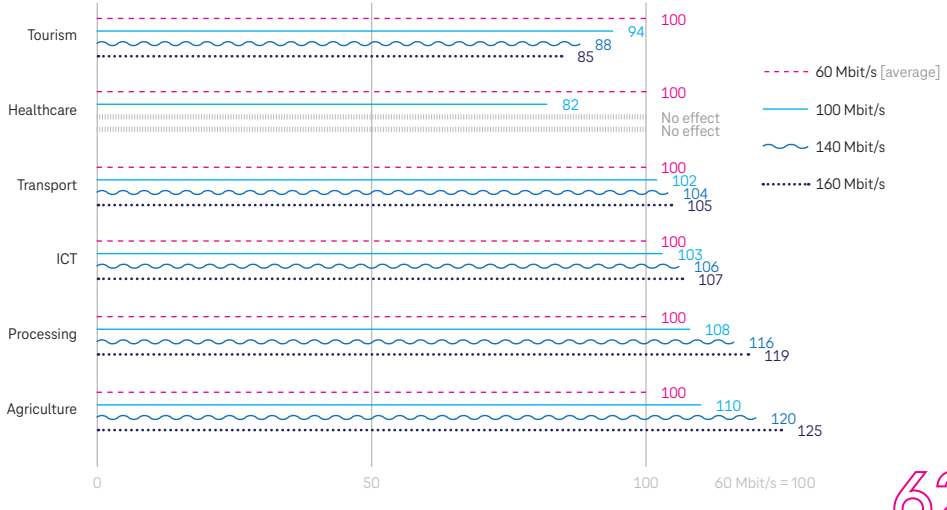
Note
The average user speed in Brod-Posavina County in the observed period was 36 Mbit/s, and the average share of new companies in the population was 14 percent. The results need to be interpreted in this context

Effects of 5G infrastructure development on business operations – Technological complexity and export sophistication

- The operating expenses index was calculated from the assessment of the effects on the share of operating expenses in total operating revenues.
- Benefits in the form of reductions in operating costs can be expected in the ICT, agriculture, and transport sectors, where expected reductions in the share of operating costs range from 0.2 in the ICT and transport sectors to 0.3 in the agricultural sector.
- In the manufacturing industry and tourism, the deployment of the 5G network can be expected to slightly increase operating costs, which can be attributed to the greater need to adapt to new technological trends in these sectors.
- Businesses in most counties should improve cost competitiveness by introducing a 5G network. The exceptions are Karlovac, Sisak-Moslavina, Vukovar-Srijem, and Bjelovar-Bilogora counties. Previously presented estimates for these counties indicate a high potential for attracting new companies and improving export sophistication, so the findings of the expected increase in operating costs should be viewed in this context.

Export sophistication (index)





Effects of 5G infrastructure development on business operations – Operating expenses

- The operating expenses index was calculated from the assessment of the effects on the share of operating expenses in total operating revenues.
- Benefits in the form of reductions in operating costs can be expected in the ICT, agriculture, and transport sectors, where expected reductions in the share of operating costs range from 0.2 in the ICT and transport sectors to 0.3 in the agricultural sector.
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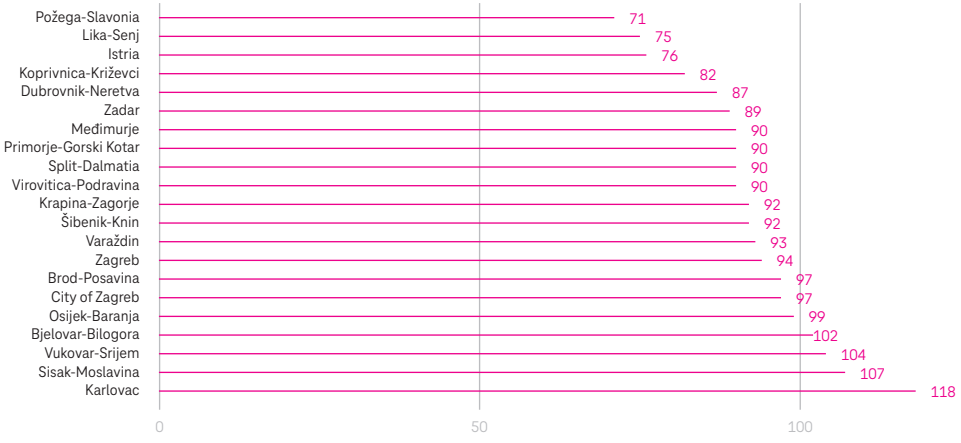
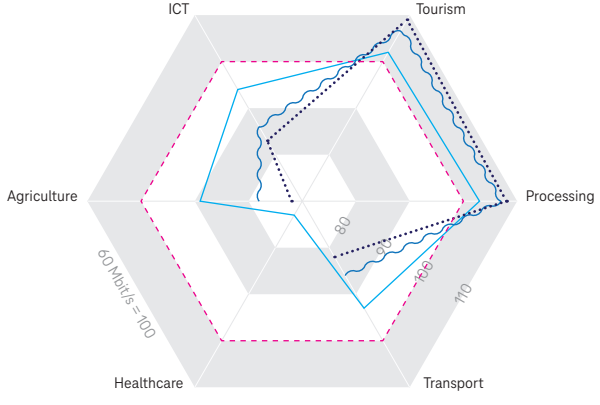
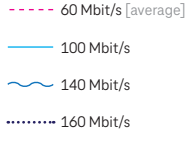
Operating expenses (index)





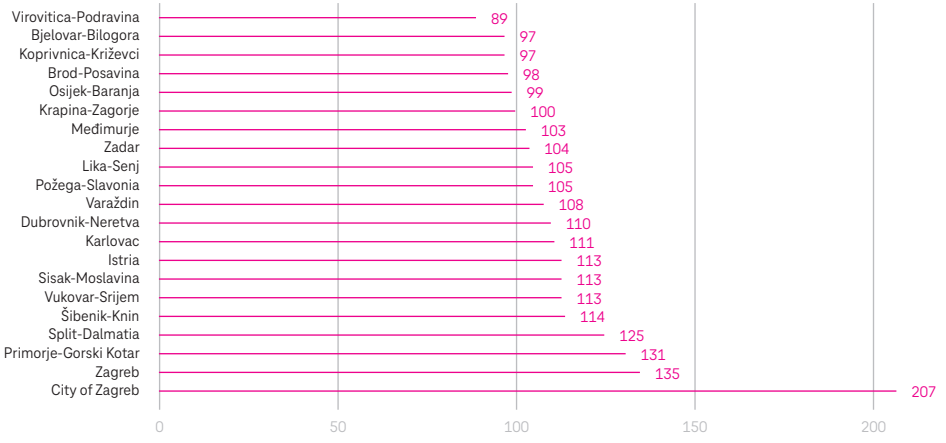


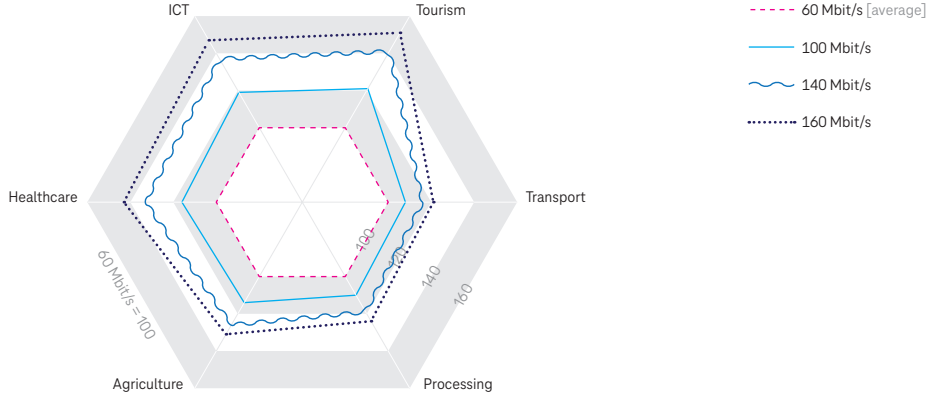
Estimates for the health sector at speeds of 140 Mbit/s and 160 Mbit/s are not statistically significant.

Effects of 5G infrastructure development on business operations – Sales revenues

- Sales revenues are expressed in millions of HRK.
- In all sectors, sales revenue is expected to increase with the deployment of the 5G network in the range of 1.2 times in processing manufacturing industry and the transport sector and up to 1.5 times in the tourism and ICT sectors.
- The City of Zagreb and Zagreb County are in the lead in terms of the expected increase in sales revenue, with the effect in the case of Zagreb being almost twice as high as in all other counties.
- The largest increase in revenues is expected in the City of Zagreb and Zagreb County, Primorje-Gorski Kotar County, and Split-Dalmatia County, i.e., the counties with the three largest urban centers in the country.
- Expectations of a slight decline in sales revenue have been identified in counties with a high potential for attracting new businesses, improving export sophistication and cost efficiency that the deployment of a 5G network could lead to structural restructuring in these regions.

Sales revenues (index)

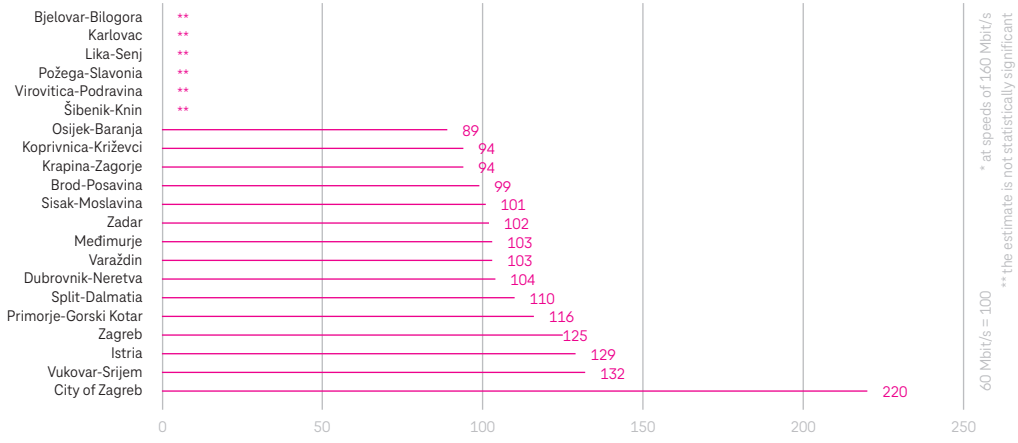


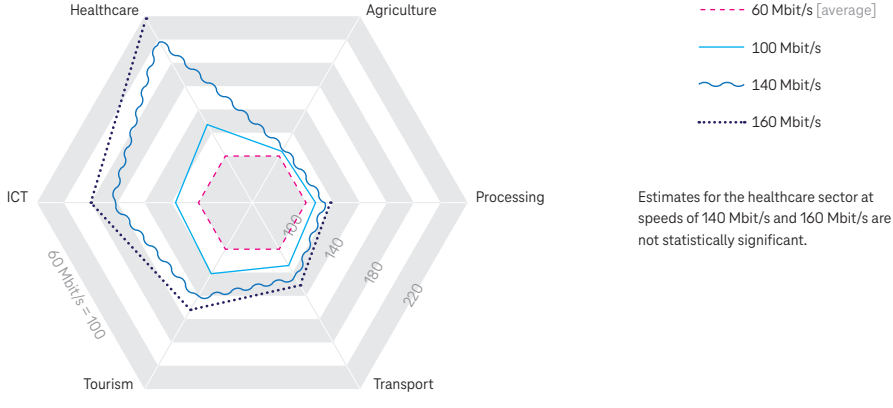


Effects of 5G infrastructure development on business operations – Export revenues

- The positive impact of the deployment of the 5G network has been assessed in all sectors except agriculture. The range of expected increase in export revenues ranges from 20 percent in the manufacturing industry to 80 percent in the ICT sector and 120 percent in healthcare services.
- ↗ No statistically significant effects of the 5G network were found in a number of counties, but an increase in export revenues is expected in most others. Here, too, the City of Zagreb leads with twice the expected effects than other regions.
- Expected increases in export revenues in other regions range from 1.01 times to 1.3 times. In several regions, results have been reported that indicate a potential decline in export earnings. These are also regions with a high potential for attracting new companies, improving export sophistication and cost efficiency, which suggests that the deployment of a 5G network in these regions could lead to a structural shift.

Export revenues (index)



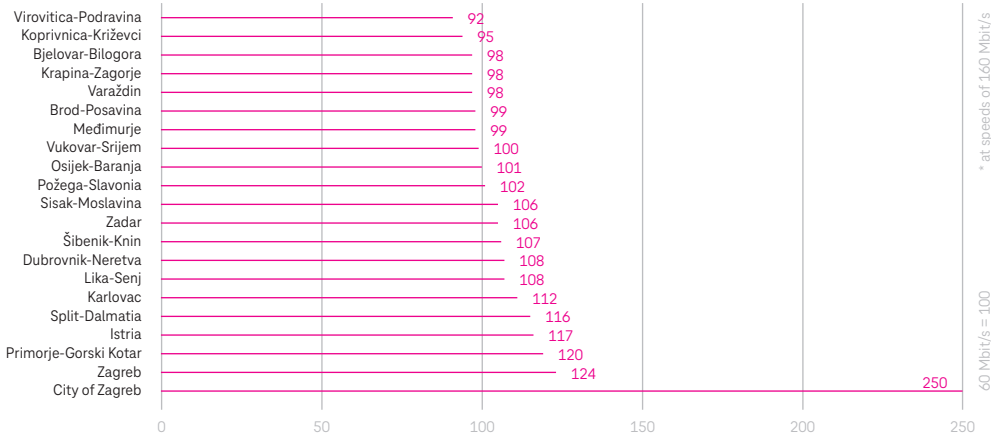


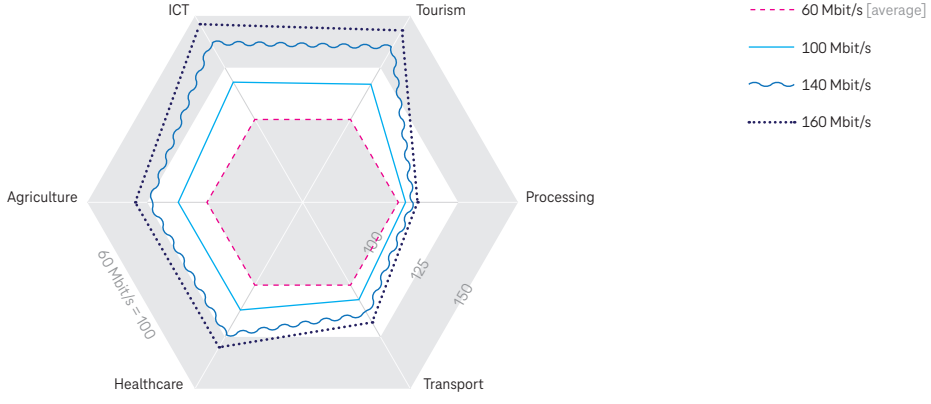
Estimates for the healthcare sector at speeds of 140 Mbit/s and 160 Mbit/s are not statistically significant.

Effects of 5G infrastructure development on businesses – Employment

- The deployment of the 5G network will bring benefits in the form of increased employment in all analyzed sectors. The range of estimated benefits ranges from an 8 percent increase in manufacturing to a high 43 percent in tourism and 46 percent in the ICT sector.
- At the county level, as in previous estimates, the highest intensity of the effect was recorded in the City of Zagreb, followed by a group of highly developed counties where the effects of the increase range from 1.16 to 1.24 times.
- Negative effects on counties with high potential for structural change are also present in employment impact assessments.

Number of employees (index)





Effects of 5G infrastructure development on businesses – Comparison with international analyses and assessments of 5G effects at the national level

- The results of the analysis indicate the existence of sectoral and regional benefits of upgrading the existing infrastructure to 5G levels identified as key to achieving growth and productivity goals.
- The deployment of the 5G network opens significant entrepreneurial potential, which is particularly evident in less developed Croatian regions and those far from major urban centers, as well as in agriculture and tourism. Such findings are in line with the findings of a recently published study by Analysys Mason (2021), according to which the greatest economic benefits of introducing a 5G network can be expected in the agricultural sector and in remote and less developed areas
- Through its potential for networking people and machines and creating digital open business and innovation platforms, the 5G network has the potential to enhance technological sophistication and the export-based competitiveness. Our findings here are in line with the Analysys Mason study (2020) and indicate the greatest benefits in the sectors of agriculture, manufacturing, and in most counties where a high potential for establishing and attracting new businesses has been previously identified. However, it should be noted that the deployment of the 5G network also leads to redistributive spatial effects. In a number of regions, the potential for reducing export sophistication has been identified, suggesting a shift to low-tech-intensive activities.
- By automating and eliminating standardized labor-intensive activities, the 5G network has the potential to improve cost competitiveness in almost all counties. The greatest potential for increasing the cost-effectiveness of operations has been identified in the ICT, agriculture, and transport sectors (up to 30 percent), which is in line with Accenture estimates (2021) for the European economy. On the other hand, it seems that the 5G network will require additional expenditures in the manufacturing and tourism sectors. These sectors in Croatia are traditionally price competitive, which reduces their potential to take advantage of the 5G network and requires adjustments to business models, market orientation, and structure.
- Estimates at the national level suggest that the deployment of a 5G network could increase export sophistication by 10 percent, reduce operating costs by 10 percent, and open the potential for up to three times the share of new businesses in the total business population. These estimates are not definitive and can be considered relatively conservative as they are based on data that can be interpreted as the lower limit of user availability of the 5G network. Although the eMBB will have a significant impact on economic activity, given that it is an improvement of the existing service, its economic impact will be less intense than the impact of MIoT and MSC use cases not assessed in this analysis.
- The effects of the introduction of the 5G network can also be distinguished with regard to the development of individual regions. In developed regions, the deployment of the 5G network has the potential to increase employment, sales, and export revenues. Such findings correspond to the existing structure of these regions. In less developed regions, the potential effects of the introduction of the 5G network will be reflected primarily in structural shifting as a precondition for achieving effects such as those identified in developed regions.
- Overall, the introduction of the 5G network has the potential to increase market dynamism, improve cost competitiveness and sophistication of the domestic economy and lead to redistributive effects of economic activity among Croatian regions.

CASE STUDY

Kutjevo

Drones and digital technologies improve viticulture

Kutjevo d.d. is one of the largest Croatian wine producers with almost 800 years of tradition of cellaring and winemaking. Cultivating 420 hectares of its plantations, it is at the forefront of business modernization, implementing a pilot project by using drones to monitor vineyard production to more efficiently, at lower costs, control variability that affects the quality of grapes. The pilot project, which will improve vineyard control, will provide Kutjevo d.d. With a number of benefits of the 5G network.

Basic information

Under the leadership of the consulting company for smart agriculture Alti Agro in cooperation with TIS Group, specializing in the development of artificial intelligence systems, and Osijek technology company Orqa specializing in the development of drone products and equipment with the network support of Hrvatski Telekom, Kutjevo d.d. implements a pilot project through which it collects data on the lushness and variability of vineyards through footage with multi-spectral cameras on drones.

Multi-spectral footage is processed with appropriate tools to support decision-making in viticulture production. In this way, it is possible to identify potential problems such as the possible occurrence of diseases and/or pests, lack of fertilizers, or the need for irrigation.

"Deploying drones and digital technologies and insights into the obtained and processed data undoubtedly lead to better assessment of yield during the monitoring of different phases of vegetation, and is especially important in recognizing vine disease and timely detection of pests. Thanks to this technology and the data transfer speed provided by the 5G network, we are improving management of our vineyards, which ultimately affects the production of premium, award-winning wines for which we are recognized"

Mirela Križanović,
Director PJ Vinogradarstvo
i vinarstvo Kutjevo d.d.

Benefits and advantages

The footage is also used to create vineyard maps that are a prerequisite for future targeted implementation of agrotechnical and ampelotechnical measures in the vineyard, and relate to the targeted use of pesticides, fertilizers, irrigation, but also selective grape harvest according to established quality zones within vineyards. These procedures can reduce production costs, increase, and regulate the yield and quality of grapes, and monitor the entire viticultural production, which allows better planning and assessment of future needs and revenues.

"The use of new available technologies in viticultural production and their adaptation to the needs of individual users is the future of modern viticultural production. Digitalization and data collection provides a better insight into the viticultural production itself and serves as a basis for improving production. The effect will be maximized by using the 5G network and faster transfer of collected and processed data."

Ivana Rendulić Jelušić,
Alti Agro, project manager

The footage will also be used to develop and train neural networks of artificial intelligence systems that will ultimately be able to replace some time-consuming and cost-intensive operations in production management. The aim of digitalization is to collect relevant data for making better decisions in viticultural production.

"With our knowledge and experience built in TIS, we want to create AI solutions to enable the presence and availability of advanced digital technologies in various areas of the economy. This project is just one such example where by using unmanned aerial vehicles, and especially artificial intelligence in viticulture and the 5G network, we want to provide a new, simpler and more advanced service to the growers themselves."

Tomislav Strgar,
TIS Grupa, AI project manager

We control the drone flight by radio and shoot the vineyard according to a pre-agreed route. As a company from the drone industry, we decided to participate in this project to show how drones can contribute to increasing the efficiency of agricultural and viticultural production and that the use of new technologies can improve production. Using the new 5G network in the future, the transfer of images from the drone will be faster and more efficient because it will be possible to do it over the network, and through the 5G network it will be possible to remotely control the flight of the drone.

Potential and challenges of the future

In the future, new generation mobile networks, such as the 5G network, will enable the collection and monitoring of significantly more data even in real time. The vineyards will be controlled from one control center, and the flight of drones will be controlled remotely, which will allow a better determination of the flight path important for the quality of vineyard images.

3.2. Economic Effects of 5G Infrastructure Development in Individual Clusters and User Cases

A wide range of effect assessments were presented by previous studies on the economic benefits of the 5G network. Those studies differ in the applied methodological approach, assumptions, the presentation of results, and other specifics. Previous studies use different methodologies, while the most used approaches are: expert opinion surveys of professionals of appropriate profiles, econometric modeling, input-output model, or a combination of different assessment methods. An increasing number of recent research uses the so-called triangulation method, i.e., a technique that combines the results of estimated effects from several previous studies and sources. This approach averages the results of previous estimates to minimize deviations in estimated effects.

Apart from the ICT sector itself, the most intensive effects of the 5G network on productivity growth in previous research are expected in the following sectors: manufacturing industry, financial services, public affairs, transport, development, utilities, and agriculture. The expected impact on other sectors such as real estate, trade, arts, and entertainment remains positive, but of lower intensity. Table 3 shows the estimates of the effect of the 5G network at the level of various activities found in previous studies. Estimates of the 5G network effects in IHS (2017) and Tech4i2 (2019) are relatively optimistic and the expected economic growth rates due to higher productivity resulting from the deployment of the 5G network range from 1 percent (arts and entertainment) to 11, 5 percent (ICT sector in IHS study, 2017). The order of sectors sorted by the intensity of effects in these two studies does not differ significantly.

Somewhat more conservative estimates are given in recent studies by STL Partners (2019) and Analysys Mason (2020) where the expected ef-

fects in growth rates associated with the deployment of 5G network are significantly lower than in previous studies. For example, for the manufacturing industry in Analysys Mason (2020), the expected effect on accelerating the growth of economic activity is only 1 percent, compared to the previous estimates which were in the range of 3 to 4.3 percent. Furthermore, Analysys Mason (2020) does not automatically apply the expected percentage growth effect to total sector activity, but only to the estimated share of units to which the 5G network is expected to be available, i.e., larger companies in relevant subsectors that have the potential to increase productivity due to 5G networks. Analysys Mason (2020) estimates the effect on other economic sectors (not listed in the table) by applying an assumption on linear increase in economic activity of 1 percent for all units that will have access to FWA or urban hotspot, depending on the territorial coverage of 5G network.

The potential effects of the development of 5G infrastructure in Croatia will largely depend on developments in the EU due to the harmonized institutional framework, the common strategic goals, availability of structural funds, and the functioning of the common market. The results presented below for effects at the level of Croatian regions and industries are largely based on the methodology and assumptions from a recent study dealing with EU countries (Analysys Mason 2020). This research is used as a basis for effect assessment in Croatia due to a conservative assumption applied in comparison to other research. Therefore, the estimates presented below can be considered as the lower limit of the potential long-term effects. The application of the same methodology as presented in Analysys Mason (2020) enables the better comparability of estimates with other EU members and provide international comparison of the position of Croatian counties regarding expected benefits of the 5G network. However, certain specifics of the Croatian economy should be also considered in the assessments. Due to the importance of tourism for the Croatian economy, in addition to the existing set of assumptions of improved economic growth of certain economic sectors because of 5G network development as presented in Analysys Mason (2020), this study also assumes the positive effects on the growth of the Croatian tourism. Effects on the growth rate of tourism industry are estimated to be 0.8 percent which is slightly lower than in comparison to the manufacturing industry. The aim of this part of the study is to pro-

vide regional distribution of costs and benefits. National effects based on the above-mentioned research are distributed at the level of Croatian counties by application of appropriate regional indicators. For this purpose, official data from the Central Bureau of Statistics (CBS) and

Table 3 **Estimated effects of 5G network availability on the growth of individual economic sectors, in%**

	Tech4i2 (2019)	IHS (2017)	STL Partners (2019)	Analysys Mason (2020)
Agriculture	3.6	6.4	1.0	2.6
Mining	2.2	4.1	4.7	1.8
Manufacturing industry	3	4.2	4.3	1.0 (adjusted for the share of larger companies in the relevant sector)
Utilities	3.6	4.5	4.7	
Development	3.3	4.7	0.8	2.4 (reduced according to 5G availability rating)
Trade	2.1	3.4	1.6	
Transport and Storage	4.1	5.6	3.5	3.0 (ports and airports)
Hotels and Restaurants	2.9	4.8		
ICT	8.1	11.5		
Finance	3.6	4.6		
Real Estate	1.7	2.4		
Professional Services, Science	3.7	3.7		
Public Administration	4.2	6.5		1.0
Education	2	3.5		
Healthcare	2.3	2.3	1.1	
Art and Entertainment	1	3.5	4	
Linear effect on other activities				1.0 (total GDP growth for units to which FWA and urban hotspots are available)

Source: Tech4i2 (2019), IHS (2017), STL Partners (2019), Analysys Mason (2020).

data from the annual business reports of entrepreneurs of the Financial Agency were used. At the county level, the CBS publishes data on the regional structure of gross value added, realized passenger traffic and freight transport at airports and seaports, regional structural business statistics, production of agricultural products and other regional statistics. In addition to official CBS data, business reports available from the Financial agency was used to estimate the proportion of entrepreneurs who due to their size and activities have greater potential for improving productivity based on the use of 5G network.

The long-term estimates are generally related to a wide range of uncertainties, especially when it comes to smaller territorial units. It should be kept in mind when interpreting the results of the estimates presented below. The entry or exit of only one large company from a region can significantly affect the total gross value added and employment of a particular county. So far, the Croatian economy has lagged behind the more advanced EU members in terms of technological progress and the speed of economic transformation. The continuation of such trends would result in less intensive economic effects of 5G deployment. The actual effects in future period, for the global and for the Croatian economy alike, may differ significantly from the estimates, depending on a number of factors which could impact the technological, social, and other processes. The economic policy makers and company management should invest significant efforts in enabling successful digital transformation of the economy and the maximization of economic benefits.

The temporal dynamics of the spread of effects can also vary. A comparison of the available results of the economic effect assessment of the deployment of the 5G network in previous research suggests the need for a certain initial period for adaptation and industrial transformation, after which there is a rapid increase in benefits until the technology is widespread. With the maturity, there is less and less room for further accelerated growth of effects, and the expected benefits are therefore expected to form s-shaped curve.

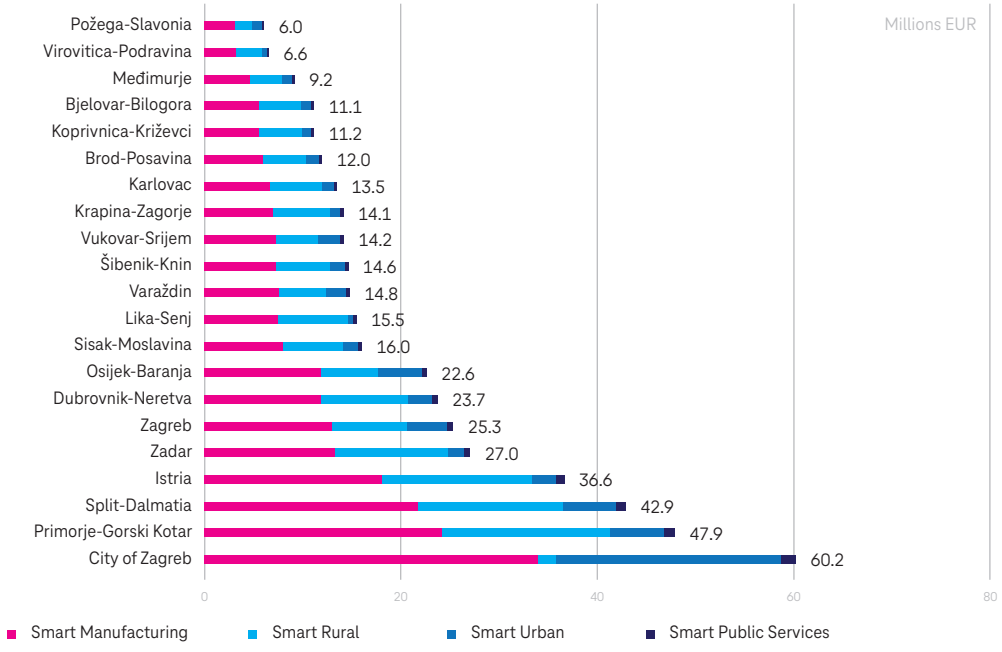
Estimation methodology – costs

- Total costs of investment in 5G network in Croatia is estimated to range from 445 (Mason, 2020) to EUR 500 million (EU, 2017).
- This paper uses the Mason (2020) estimate, which in addition to total investments in the 5G network contains a more detailed breakdown of costs into four basic clusters (Smart Manufacturing and Logistics, Smart Rural, Smart Urban, and Smart Public Services).
- The model used to estimate the cost of creating a 5G network is described in detail in Mason (2020) and is based on numerous parameters: the cost of required components, geographic characteristics, and other inputs.
- Hrvatski Telekom assessed the breakdown of the cost structure by Croatian counties. For each cluster, the structure of required investments by counties was estimated, having in mind demographic, geographical, and socio-economic characteristics.
- Although in absolute terms the largest investments are estimated for the City of Zagreb, in relative terms (investments per capita and as a percentage of GDP), investments will be most intensive in sparsely populated areas, such as Lika-Senj County and counties alongside the Adriatic with sparsely populated hinterland and islands.

Table 4 **Investments in the 5G network in Croatia, relative indicators**

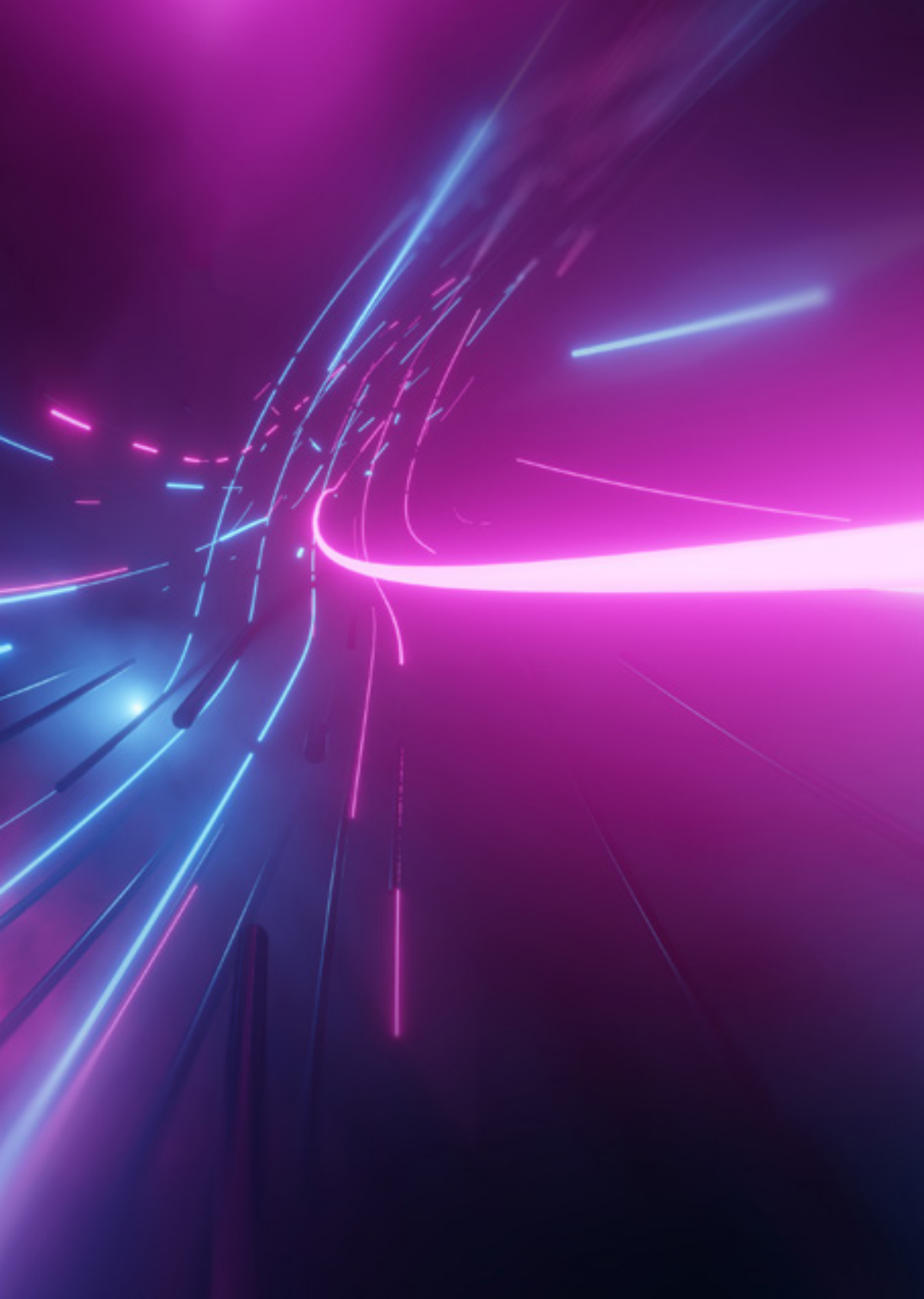
County	Investments per capita	Investments as %of GDP
Lika-Senj	351.7	3.6
Dubrovnik-Neretva	193.3	1.5
Istria	174.2	1.2
Primorje-Gorski Kotar	170.3	1.1
Zadar	161.1	1.5
Šibenik-Knin	148.4	1.4
Karlovac	118.0	1.3
Krapina-Zagorje	114.0	1.4
Sisak-Moslavina	111.7	1.2
Bjelovar-Bilogora	106.1	1.2
Koprivnica-Križevci	106.0	1.1
Split-Dalmatia	95.8	1.0
Vukovar-Srijem	95.6	1.2
Požega-Slavonia	92.7	1.2
Virovitica-Podravina	91.0	1.2
Varaždin	89.7	0.8
Brod-Posavina	88.3	1.2
Međimurje	84.2	0.8
Osijek-Baranja	84.0	0.9
Zagreb	81.8	0.8
City of Zagreb	74.3	0.3

Estimation of total investments in 5G network



Estimation methodology – benefits

- The benefits to the Croatian economy and counties are based on Analysys Mason (2020) methodology which quantifies the economic effects of achieving the goals of the existing Action Plan for the introduction of 5G in Europe (5GAP), which seeks to ensure the availability of 5G network in all urban areas and major transport routes by 2025.
- Benefit-cost analysis encompasses the achievement of updated goals in the field of 5G network, taking into account the experience of 5G pilot projects and the potential for technological development and productivity growth based on the use of 5G network.
- The baseline projection of the GDP growth of the Republic of Croatia until 2025 is based on the IMF's World Economic Outlook Database, while for later periods (2025 – 2040) the average expected growth rate for the period 2018 to 2025 was used, which in the case of Croatia is 1.8 percent.
- It was assumed that the structure of the Croatian economy and the counties would not change significantly in the projected period.
- For each activity, the potential benefits related to 5G network was calculated by applying the percentage increase in gross value added from Table 3 (last column) showing the assumptions from Analysys Mason (2020). within addition, benefits in the tourism sector (hotels and restaurants) are also included with an expected productivity growth of 0.8 percent for the period from 2030 to the end of the projected period.
- In accordance with the conclusions of previous research, an adjustment period is assumed in the period from 2025 to 2030 in which the benefits gradually increase from zero to full potential after 2030.
- The costs and benefits of future periods have been scaled down to net present value in 2020 by applying an annual discount rate of 6%. The benefit in terms of net present value from later years for each estimated component is divided by a factor (1+0.06), where n is the number of years from 2020 to the target year. In future, since this is a long-term period, the discount factor significantly affects the net present value, and the correction factor for 2040 is greater than 3.
- For comparability with the results of other countries, estimated benefits have been reconciliated to the baseline scenario presented in Analysys Mason (2020). for all benefits except hotels and restaurants. The main goal of this research is to distribute the values from this study to Croatian counties based on the structural characteristics of individual counties according to data on business operations of entrepreneurs and the structure of GVA according to CBS data.
- Costs and benefits are summarized in the following four clusters:
  - Smart Manufacturing and Logistics (industry, ports, airports, mining, tourism)
  - Smart Rural (Agriculture, FWA)
  - Smart Urban (development, hotspots)
  - Smart Public Services



Investment costs and benefits in the Smart Manufacturing and Logistics cluster

- The benefit/cost ratio from the application of 5G technology is the most favorable for the Istria County, which in addition to developed tourism also has a developed manufacturing industry.
- The highest level of net benefits per capita is expected in Istria, Dubrovnik-Neretva County, and the City of Zagreb.
- In principle, less developed counties, especially those in which the high amount of investments is required, such as Lika-Senj, Vukovar-Srijem, Bjelovar-Bilogora, and Virovitica-Podravina counties within the Smart Production cluster will not achieve a sufficient benefit to cover investment costs, without additional measures of regional and industrial policy oriented to improvement of the technological level of the economy of such regions.
- The counties along the Adriatic Sea can derive the most significant value of benefits within this cluster from increasing productivity in tourism and using new opportunities for promotion and sophisticated services.

Ratio of costs and benefits by counties in the Smart Manufacturing and Logistics cluster

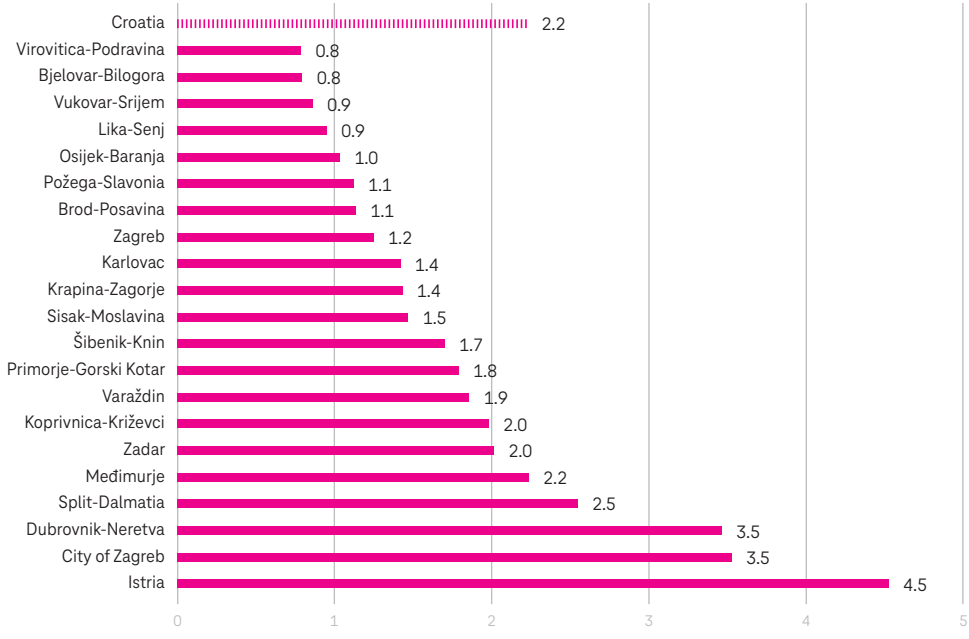


Table 5 **Investment costs and benefits in the Smart Manufacturing and Logistics cluster**

	Costs, mil. EUR	Benefits, mil. EUR	Ratio	Net benefit per capita EUR, anually	Net benefit %GDP 2021
Istria	18.1	81.9	4.5	20.2	2.0
City of Zagreb	33.9	119.6	3.5	7.1	0.5
Dubrovnik-Neretva	11.9	41.2	3.5	15.9	1.8
Split-Dalmatia	21.8	55.4	2.5	5.0	0.8
Međimurje	4.6	10.3	2.2	3.5	0.5
Zadar	13.3	26.8	2.0	5.4	0.8
Koprivnica- Križevci	5.6	11.0	2.0	3.5	0.6
Varaždin	7.6	14.1	1.9	2.6	0.3
Primorje-Gorski kotar	24.2	43.3	1.8	4.5	0.4
Šibenik-Knin	7.3	12.4	1.7	3.5	0.5
Sisak-Moslavina	8.1	11.8	1.5	1.7	0.3
Krapina-Zagorje	7.0	10.0	1.4	1.6	0.3
Karlovac	6.7	9.6	1.4	1.6	0.3
Zagreb	13.0	16.3	1.2	0.7	0.1
Brod-Posavina	6.0	6.8	1.1	0.4	0.1
Požega-Slavonia	3.1	3.5	1.1	0.4	0.1
Osijek-Baranja	11.8	12.2	1.0	0.1	0.0
Lika-Senj	7.6	7.2	0.9	-0.6	-0.1
Vukovar-Srijem	7.3	6.3	0.9	-0.5	-0.1
Bjelovar-Bilogora	5.6	4.4	0.8	-0.7	-0.1
Virovitica-Podravina	3.3	2.6	0.8	-0.7	-0.1
Croatia	228.0	506.8	2.2	4.6	0.54

- The most significant benefits within the Smart Manufacturing and Logistics cluster are expected in the increase in the gross value added of the manufacturing industry.
- The benefits of the manufacturing industry are greatest in more developed counties, which have a higher share of larger companies in the technologically more advanced sectors of the manufacturing industry, where the potential for productivity growth based on the use of IoT is higher.
- The potential benefits for ports and airports are not significant in monetary values and are limited to a few locations specializing in such activities.
- The importance of mining for the Croatian economy is not pronounced and no significant benefits are expected from this segment.
- The potential for realizing the benefits of providing new tourist services and improving marketing activities is greatest for the counties of Adriatic Croatia.
- In all counties along the Adriatic Sea, a higher level of benefits is expected from the opportunities provided by 5G for the growth of tourism than from the improvement of the productivity of the manufacturing industry.
- Expected benefits within the Smart Manufacturing and Logistics cluster are lowest for Slavonia and other continental counties where the share of manufacturing and tourism in gross value added is low compared to other European countries (estimate given in Mason, 2020), the benefit-cost ratio in Croatia is positive, albeit relatively low.
- The reason for this is the unfavorable economic structure with a lower share of production of high-tech products and slower adoption of technological progress compared to more advanced EU countries.

Table 6 **Structure of benefits in the Smart Manufacturing by counties cluster, millions EUR**

	Processing ind.	Ports	Airports	Mining	Tourism	Total
Bjelovar-Bilogora	4	0	0	0.000	1	5
Brod-Posavina	6	0	0	0.000	0	7
Dubrovnik-Neretva	7	0	5	0.001	29	41
City of Zagreb	78	0	6	0.010	36	120
Istria	14	0	1	0.000	66	82
Karlovac	8	0	0	0.000	2	10
Koprivnica-Križevci	10	0	0	0.000	1	11
Krapina-Zagorje	9	0	0	0.001	1	10
Lika-Senj	4	0	0	0.001	3	7
Međimurje	9	0	0	0.000	2	10
Osijek-Baranja	10	0	0	0.000	2	12
Požega-Slavonia	3	0	0	0.000	0	4
Primorje-Gorski kotar	16	3	0	0.000	23	43
Sisak-Moslavina	11	0	0	0.000	1	12
Split-Dalmatia	18	2	6	0.001	30	55
Šibenik-Knin	5	0	0	0.000	7	12
Varaždin	12	0	0	0.001	2	14
Virovitica-Podravina	2	0	0	0.000	0	3
Vukovar-Srijem	6	0	0	0.000	1	6
Zadar	9	4	1	0.000	12	27
Zagreb	14	0	0	0.001	3	16
Croatia	256	10	19	0.017	222	507

*Due to rounding, the sum of the components is not necessarily equal to the total amount shown in the table

Investment costs and benefits in the Smart Rural cluster

- The benefits of the Smart Rural cluster include the additional gross value added that can potentially be achieved by increasing productivity in agriculture, and the use of 5G FWA technology, which provides the opportunity to economic growth in many industries and areas.
- As expected, the benefit-cost ratio in this cluster is most favorable for counties with a higher share of rural population, while the least benefits can potentially be realized in the most developed counties. In this way, investments in this cluster contribute to more balanced regional development and ensure high social benefits.
- According to previous research, due to the relatively low population density in rural areas, the commercial viability of development a 5G network from the point of view of private telecommunications companies is often uncertain, and to ensure social benefits a certain share in the cost of the network development should be funded from government budget.

Net benefit by counties expressed as % of the current level of GDP in the Smart Rural cluster

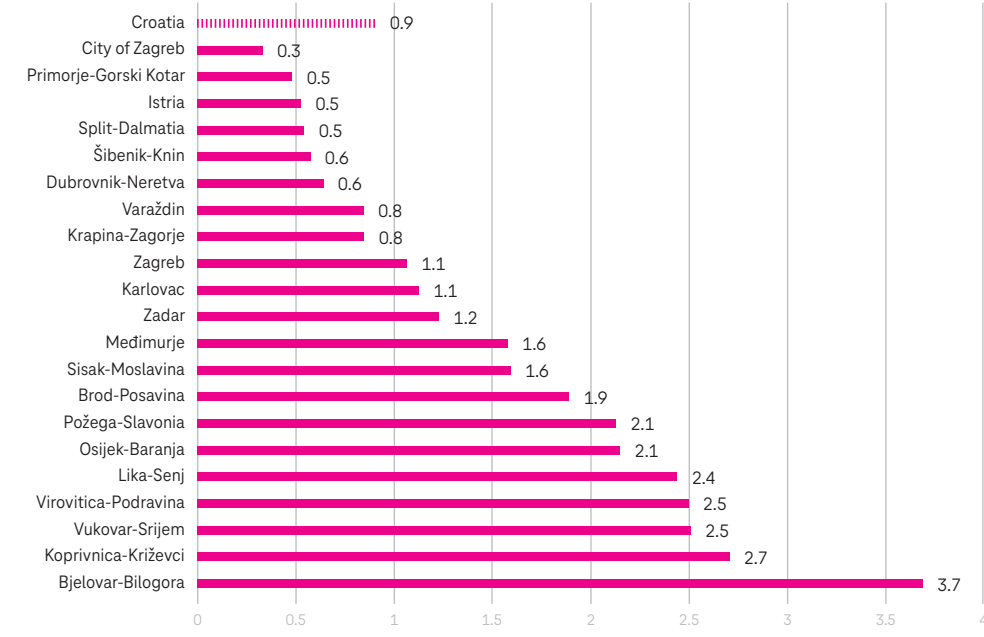
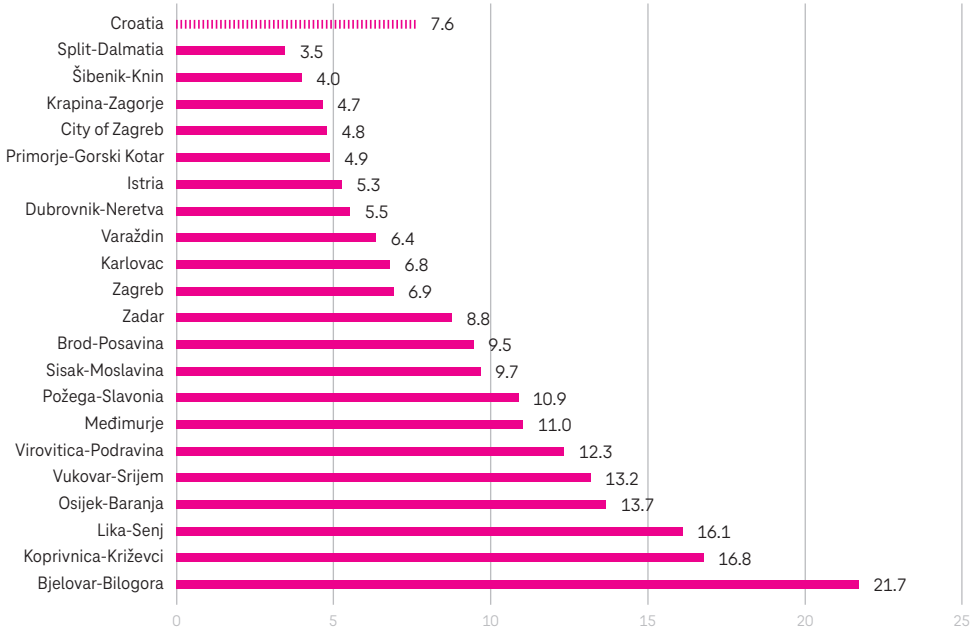


Table 7 **Investment costs and benefits in the Smart Rural cluster**

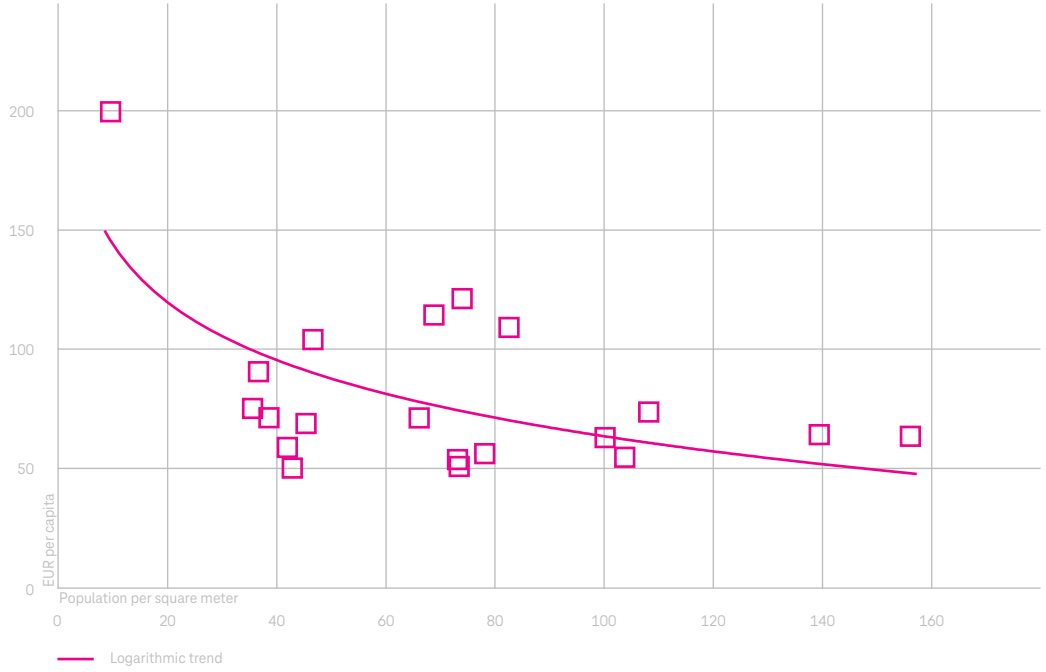
	Costs, mil. EUR	Benefits, mil. EUR	Ratio	Net benefit per capita EUR, anually	Net benefit %GDP 2021
Bjelovar-Bilogora	4.3	38.4	9.0	21.7	3.7
Koprivnica-Križevci	4.4	30.9	7.1	16.8	2.7
Vukovar-Srijem	4.3	33.6	7.9	13.2	2.5
Virovitica-Podravina	2.5	15.9	6.3	12.3	2.5
Lika-Senj	7.1	17.7	2.5	16.1	2.4
Osijek-Baranja	5.8	61.1	10.5	13.7	2.1
Požega-Slavonia	1.7	12.3	7.3	10.9	2.1
Brod-Posavina	4.4	23.6	5.4	9.5	1.9
Sisak-Moslavina	6.0	26.9	4.5	9.7	1.6
Međimurje	3.3	21.4	6.4	11.0	1.6
Zadar	11.5	33.6	2.9	8.8	1.2
Karlovac	5.2	16.9	3.2	6.8	1.1
Zagreb	7.6	39.7	5.2	6.9	1.1
Krapina-Zagorje	5.8	14.5	2.5	4.7	0.8
Varaždin	4.8	20.6	4.3	6.4	0.8
Dubrovnik-Neretva	8.8	19.0	2.2	5.5	0.6
Šibenik-Knin	5.6	11.5	2.1	4.0	0.6
Split-Dalmatia	14.7	37.9	2.6	3.5	0.5
Istria	15.3	31.9	2.1	5.3	0.5
Primorje-Gorski kotar	17.1	37.7	2.2	4.9	0.5
City of Zagreb	1.8	60.0	33.1	4.8	0.3
Croatia	142.0	605.0	4.3	7.6	0.9

Annual net benefit per capita in EUR estimated for the Smart Rural cluster



- The potential net benefit per capita in this cluster is greatest for Bjelovar-Bilogora and Koprivnica-Križevci counties, while the smallest benefit is expected in the Adriatic counties and the City of Zagreb.
- Although population density is not the only factor influencing the costs and benefits of development an FWA network, it can be seen that counties with lower population density benefit relatively more from this technology. As the costs of a fixed network provided by high-speed Internet are relatively high, without the development of FWA infrastructure, such regions would not be able to realize full potential of the 5G network.

Relationship between population density and FWA benefits



Investment costs and benefits in the Smart Urban cluster

- The benefit/cost ratio in the Smart Urban cluster is more favorable compared to the Smart Manufacturing cluster, but lower than expected in the Smart Rural cluster.
- The expected net benefit per capita is the highest for the City of Zagreb, where it is estimated at an average of EUR 4.8 per year. The City of Zagreb is also in the lead in terms of benefits as a percentage of GDP, although the range of benefits according to this indicator is relatively narrow.
- Somewhat higher net benefits are expected in counties with a higher share of urban population.
- In rural areas, the benefit/cost ratio within this cluster is lower than average, as the benefits are limited to smaller urban centers within these regions.

Net benefit by counties expressed as % of the current level of GDP in the Smart Urban cluster

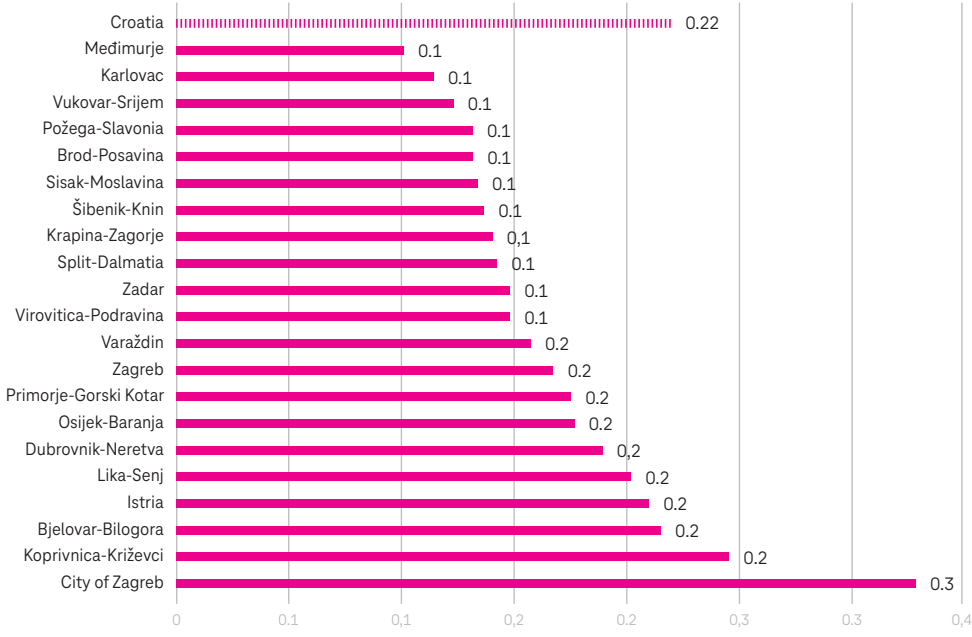


Table 8 **Investment costs and benefits in the Smart Urban cluster**

	Costs, mil. EUR	Benefits, mil. EUR	Ratio	Net benefit per capita, EUR, anually	Net benefit %GDP 2021
Bjelovar-Bilogora	1	3	2.9	1.3	0.2
Brod-Posavina	1	3	2.0	0.7	0.1
Dubrovnik-Neretva	2	5	2.2	1.6	0.2
City of Zagreb	23	81	3.5	4.8	0.3
Istria	2	9	3.7	2.1	0.2
Karlovac	1	2	2.0	0.7	0.1
Koprivnica-Križevci	1	3	3.5	1.5	0.2
Krapina-Zagorje	1	2	2.4	0.8	0.1
Lika-Senj	1	1	2.7	1.3	0.2
Međimurje	1	2	2.2	0.7	0.1
Osijek-Baranja	4	9	2.0	1.1	0.2
Požega-Slavonia	1	2	1.6	0.7	0.1
Primorje-Gorski kotar	6	13	2.4	1.8	0.2
Sisak-Moslavina	2	3	2.1	0.8	0.1
Split-Dalmatia	5	12	2.1	0.9	0.1
Šibenik-Knin	1	3	2.0	1.0	0.1
Varaždin	2	5	2.4	1.2	0.2
Virovitica-Podravina	1	1	2.3	0.7	0.1
Vukovar-Srijem	2	4	1.6	0.6	0.1
Zadar	2	4	2.7	1.1	0.1
Zagreb	4	9	2.2	1.1	0.2
Croatia	65	178	2.7	1.9	0.2

Investment costs and benefits in the Smart Public Services cluster

- Investments and benefits within the Smart Public Services cluster are of lower intensity compared to other clusters if conservative methodology is applied. The potential of applying 5G technology in some public services, such as healthcare or education, could be multiple with the full digital transformation of public administration, and the actual future benefits will depend on a number of factors that are currently difficult to assess.
- Distribution of benefits within the Smart Public Services cluster reflects the share of the public sector in individual counties, and the net benefit is again the largest for the City of Zagreb, due to concentration of many public institutions in capital city.
- The benefits in relation to the costs in this cluster are relatively high, and by designing a broader set of measures for the use of the 5G network in the public sector, greater benefits can be provided in the future.

Benefit-cost ratio in the Smart Public Services cluster

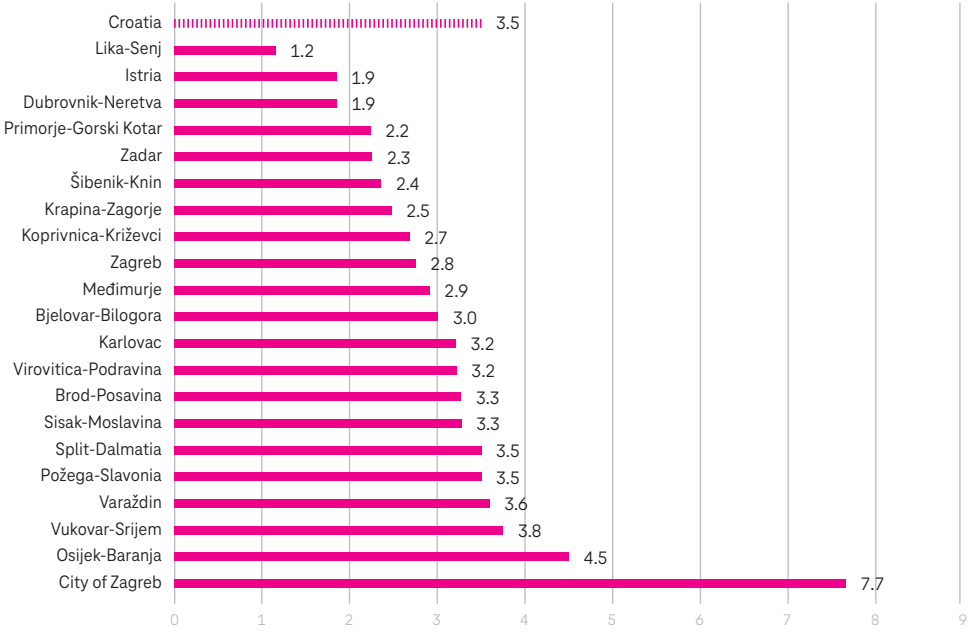


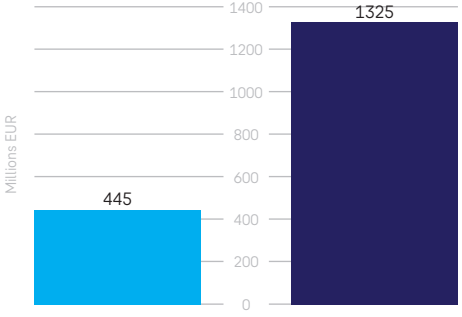
Table 9 **Investment costs and benefits in the Smart Public Services cluster**

	Costs, mil. EUR	Benefits, mil. EUR	Ratio	Net benefit per capita, EUR, anually	Net banefit, %GDP 2021
Bjelovar-Bilogora	0	1	3.0	0.3	0.1
Brod-Posavina	0	1	3.3	0.3	0.1
Dubrovnik-Neretva	1	1	1.9	0.2	0.0
City of Zagreb	1	11	7.7	0.8	0.1
Istria	1	1	1.9	0.2	0.0
Karlovac	0	1	3.2	0.4	0.1
Koprivnica-Križevci	0	1	2.7	0.3	0.0
Krapina-Zagorje	0	1	2.5	0.2	0.0
Lika-Senj	0	0	1.2	0.1	0.0
Međimurje	0	1	2.9	0.2	0.0
Osijek-Baranja	1	2	4.5	0.5	0.1
Požega-Slavonia	0	0	3.5	0.4	0.1
Primorje-Gorski kotar	1	2	2.2	0.3	0.0
Sisak-Moslavina	0	1	3.3	0.4	0.1
Split-Dalmatia	1	3	3.5	0.4	0.1
Šibenik-Knin	0	1	2.4	0.3	0.0
Varaždin	0	1	3.6	0.3	0.0
Virovitica-Podravina	0	0	3.2	0.3	0.1
Vukovar-Srijem	0	1	3.8	0.4	0.1
Zadar	1	1	2.3	0.3	0.0
Zagreb	1	2	2.8	0.2	0.0
Croatia	10	35	3.5	0.4	0.0

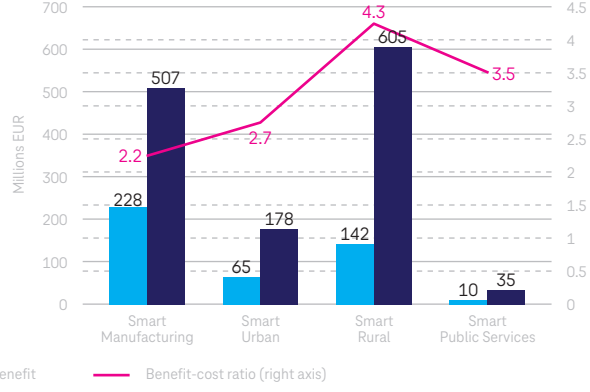
Total investment costs and benefits of 5G deployment

- Total costs and benefits are based on conservative assumptions (Mason, 2020). As tourism plays a significant role in Croatian economy, regional estimates include expected benefits related to the use of 5G network in tourism sector which, is in line with previous literature and econometric modeling results.
- The total benefits of investing in the 5G network in terms of net present value in the total Croatian economy are estimated at EUR 1.33 billion, three times more than the investment costs, which will amount to around EUR 445 million.
- The largest value of benefits with the most favorable benefit-cost ratio is expected in the Smart Urban cluster, where each EUR of investment is estimated to induce 4.3 EUR of benefits.
- With the continued lag in the speed of acceptance of modern technological processes of the domestic economy, especially the manufacturing industry compared to more advanced European countries, it is estimated that despite the highest investment in the Smart Manufacturing cluster, the result will be a relatively low benefit/cost ratio of 2.2. which is less compared to other clusters.
- A relatively high benefit/cost ratio is also expected in the Smart Public Services cluster, where an investment of EUR 10 million can generate 3.5 times the benefit.
- Almost triple the amount of benefits from costs can be expected in the smart Urban cluster in terms of the use of urban hot-spot networks and opportunities to optimize certain urban systems.

Investment costs and benefits of 5G deployment



Costs and benefits per cluster



- The net benefits of 5G deployment vary significantly by county, given the current economic structure that reflects the potential for benefits, but also demographic and geographical characteristics, such as population density, terrain, and other natural features that determine the level of costs.
- The highest level of net benefits per capita and as a share of GDP is expected in Koprivnica-Križevci and Bjelovar-Bilogora counties, which in addition to a high share of agriculture have a number of industrial companies that can benefit by increasing productivity.
- Investments in the 5G network could also result in the reduction of regional inequalities with the expected greater positive effects in less developed rural areas compared to more developed regions. In terms of GDP, more developed counties such as the City of Zagreb and Primorje-Gorski Kotar County will benefit somewhat less than less developed Slavonian counties.

Net benefit by counties expressed as % of the current level of GDP

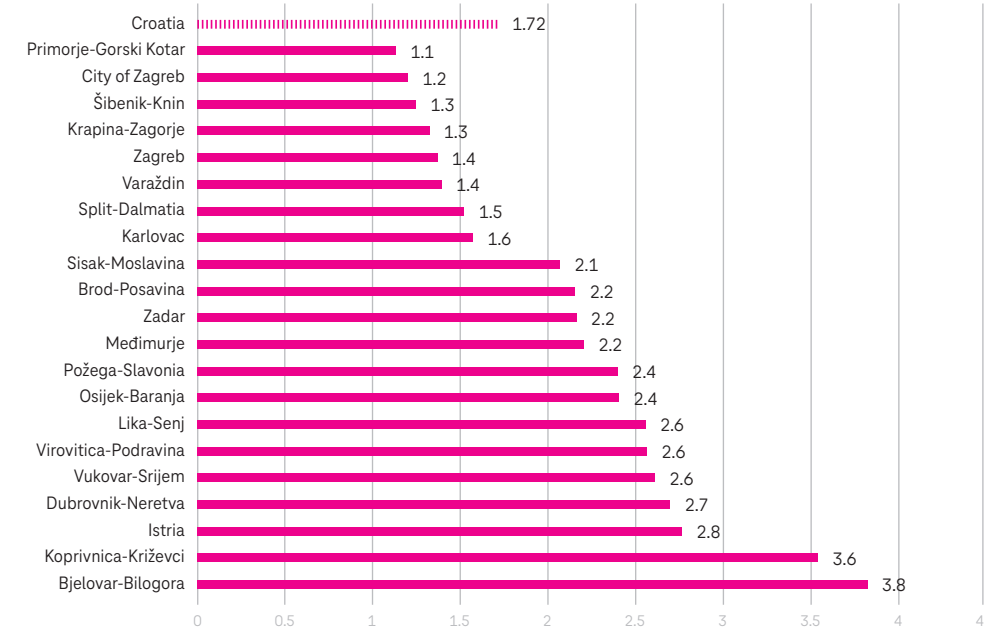
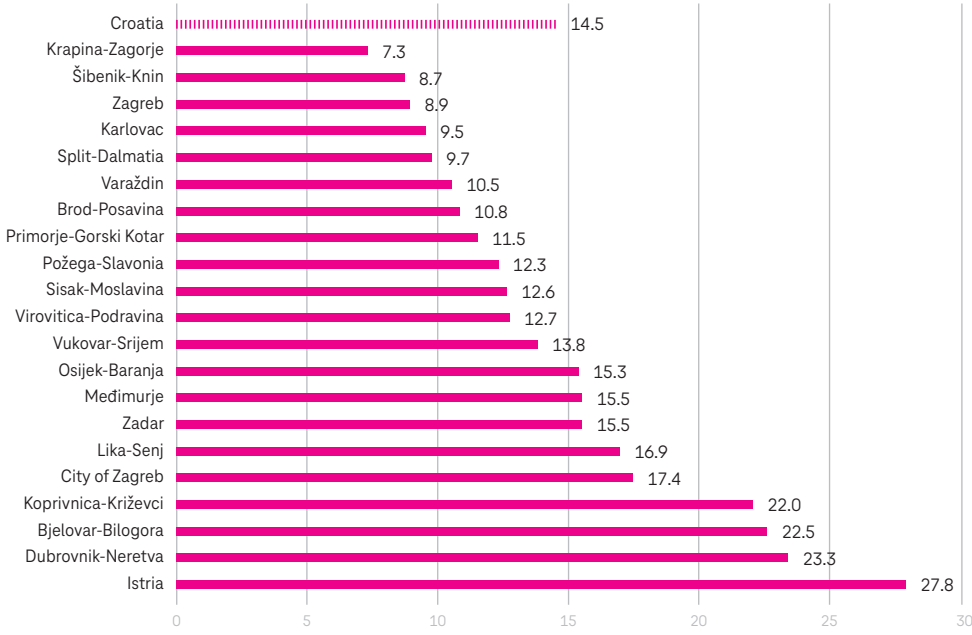


Table 10 **Total investment costs and benefits of 5G deployment**

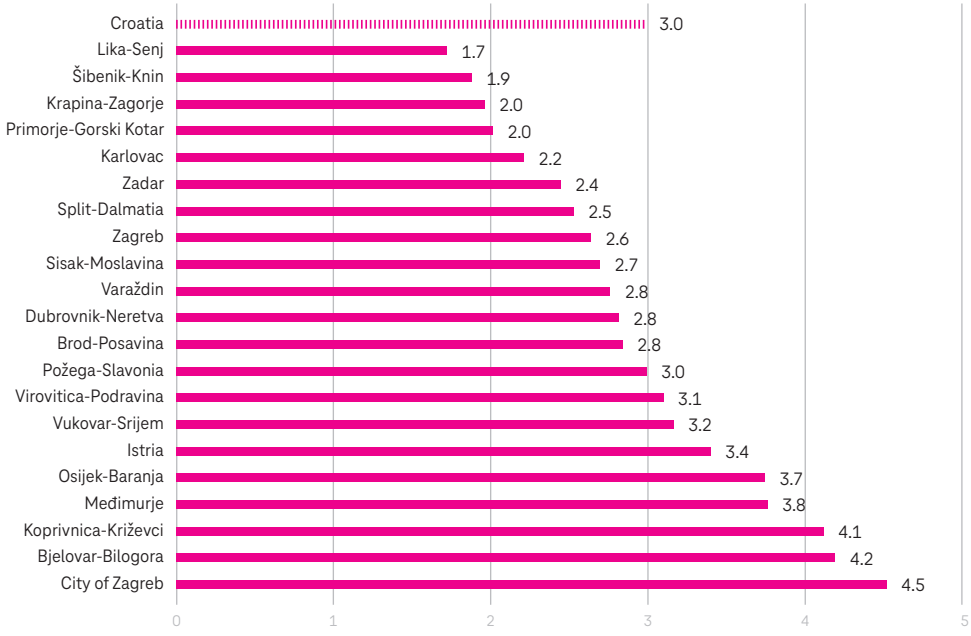
	Costs, mil. EUR	Benefits, mil. EUR	Ratio	Net benefit per capita, EUR, anually	Net banefit, %GDP 2021
Bjelovar-Bilogora	11.1	46.6	4.2	22.5	3.8
Koprivnica-Križevci	11.2	45.9	4.1	22.0	3.6
Istria	36.6	124.3	3.4	27.8	2.8
Dubrovnik-Neretva	23.7	66.6	2.8	23.3	2.7
Vukovar-Srijem	14.2	44.8	3.2	13.8	2.6
Virovitica-Podravina	6.6	20.4	3.1	12.7	2.6
Lika-Senj	15.5	26.7	1.7	16.9	2.6
Osijek-Baranja	22.6	84.7	3.7	15.3	2.4
Požega-Slavonia	6.0	18.0	3.0	12.3	2.4
Međimurje	9.2	34.4	3.8	15.5	2.2
Zadar	27.0	66.0	2.4	15.5	2.2
Brod-Posavina	12.0	33.9	2.8	10.8	2.2
Sisak-Moslavina	16.0	43.2	2.7	12.6	2.1
Karlovac	13.5	29.8	2.2	9.5	1.6
Split-Dalmatia	42.9	108.2	2.5	9.7	1.5
Varaždin	14.8	40.9	2.8	10.5	1.4
Zagreb	25.3	66.7	2.6	8.9	1.4
Krapina-Zagorje	14.1	27.7	2.0	7.3	1.3
Šibenik-Knin	14.6	27.5	1.9	8.7	1.3
City of Zagreb	60.2	271.7	4.5	17.4	1.2
Primorje-Gorski kotar	47.9	96.3	2.0	11.5	1.1
Croatia	445.0	1324.6	3.0	14.5	1.72

Net benefit per capita, EUR per year per county



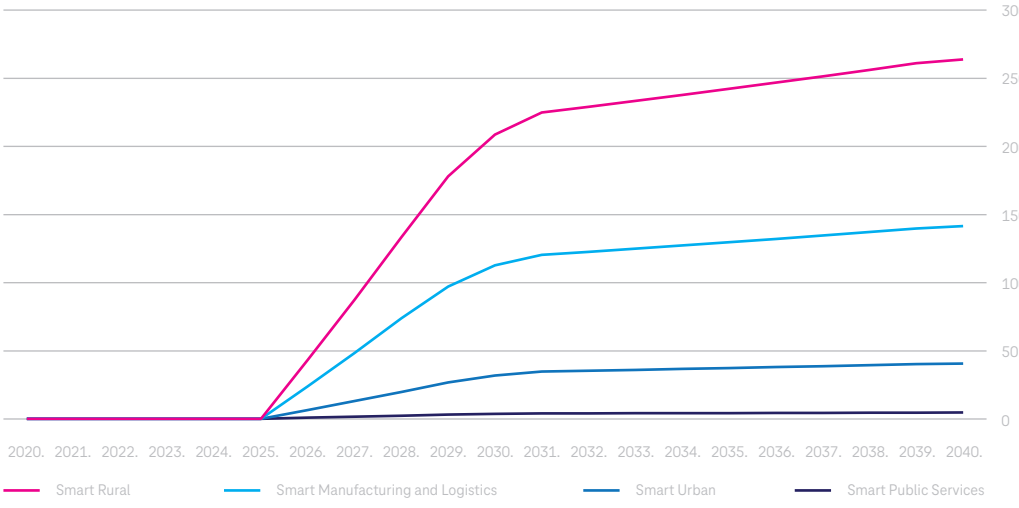
- In terms of annual net benefit per capita, the Istria County will have the greatest benefit from the development of the 5G network with EUR 27.8, while Krapina-Zagorje County could achieve only EUR 7.3 per capita per year which is almost four times less than Istria County due to unfavorable current economic structure.
- High investment costs due to the territory size and low population density along with an unfavorable economic structure are the reason for the estimated lowest benefit-cost ratio in Lika-Senj County. On the other hand, the City of Zagreb, as a densely populated area, a relatively developed manufacturing industry and a centralized public administration, could achieve the most favorable benefit-cost ratio.

Total benefit-cost ratio by counties



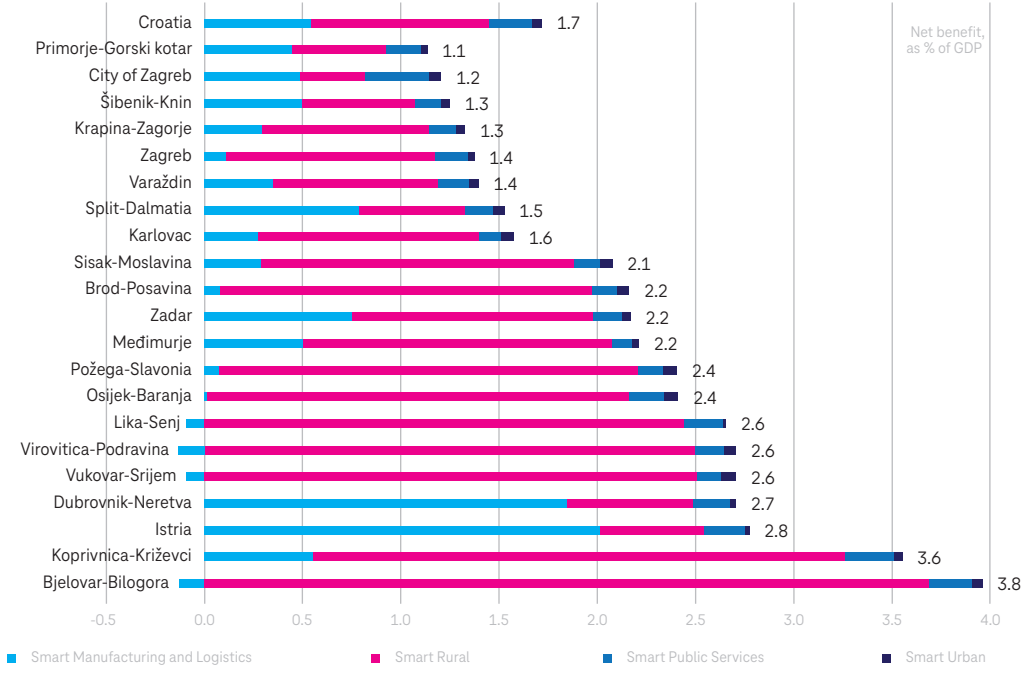
- According to previous research, a gradual increase in benefits is assumed in the period of economic adjustment to the new opportunities provided by the 5G network (2025 – 2030) until the full potential is realized, after which the benefits are realized in proportion to the growth of overall economic activity.
- The actual curve of acceptance of new technological opportunities in different clusters is likely to be different: sectors that are rapidly adopting modern technologies in production processes will reach their full potential faster than traditional sectors where technological progress is usually slow.
- Delays in the development of 5G infrastructure may delay the realization of benefits for the future. As previous research suggests, certain clusters like Smart Public Services and Smart Rural will to some extent require co-financing from public funds, as due to lower population density and fewer number of entrepreneurs, such investments, despite the potential for social benefits, will not generate enough revenue for telecommunications companies to cover investment costs.
- As relatively conservative estimates have been applied in the assessment, the potential for 5G network benefits may be more intense, especially in the Smart Manufacturing and Logistics clusters in case of more successful technological transformation of industry and other economic sectors and Smart Public Services if public institutions adapt their activities to new opportunities.

Net benefit per capita, EUR per year per county

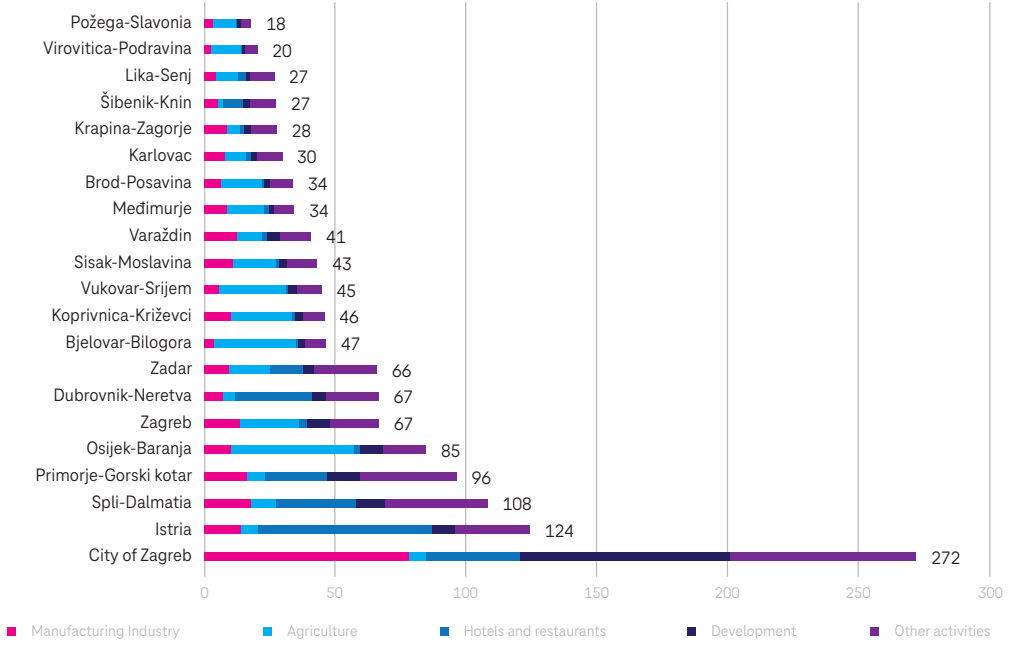


- The structure of expected net benefits differs significantly by Croatian counties. The more industrially developed counties and regions along the Adriatic Sea will achieve a relatively higher share of net benefits by increasing productivity in the Smart Manufacturing and Logistics cluster.
- Less developed rural areas will benefit economically from the 5G network by productivity growth within the Smart Rural cluster.
- The distribution of net benefits in the Smart Urban and Smart Public Services clusters shows a much more uniform structure of net benefits compared to the other two clusters, but the effects are currently lower.
- The costs of development 5G infrastructure within the Smart Manufacturing and Logistics cluster are higher than the benefits in poorly industrialized and technologically developed counties such as Lika-Senj, Virovitica-Podravina, and Vukovar-Srijem counties.

Structure of benefits by clusters and counties



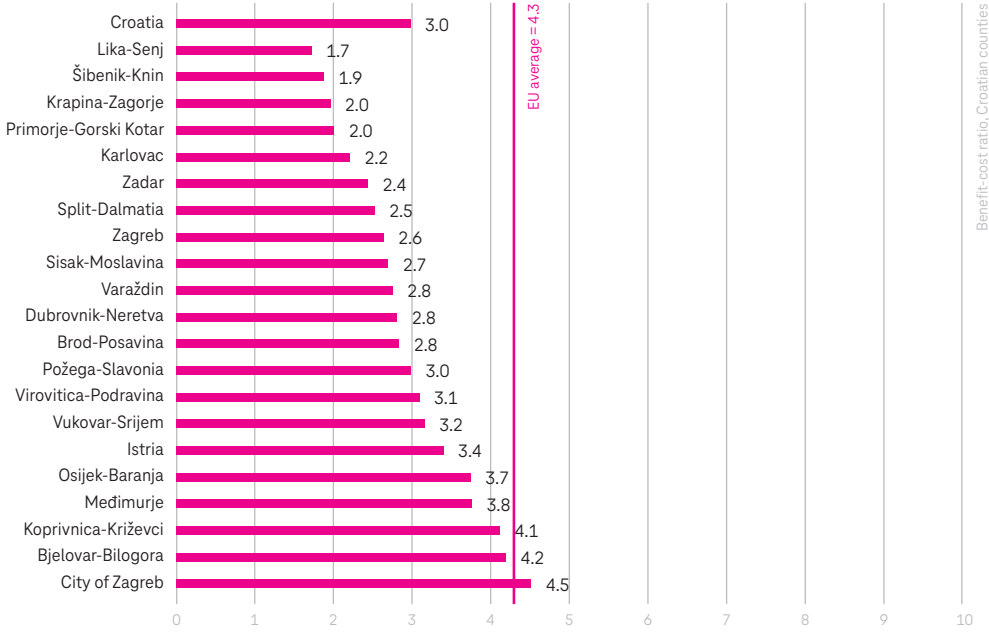
Structure of total benefits by activities and counties, million EUR of growth of gross value added in the period up to 2040 are reduced to net present value



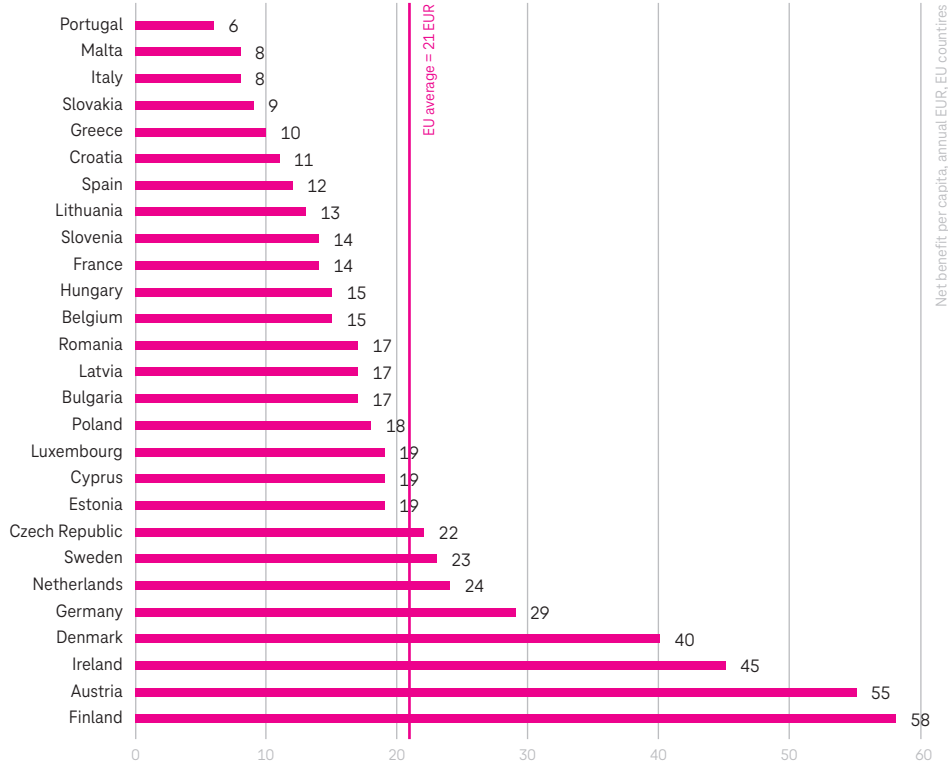
International comparison of benefit-cost ratio

- Croatia is positioned in the group of countries that are expected to be less efficient in using the new opportunities provided by 5G networks, and only for the City of Zagreb is the benefit-cost ratio expected above the EU average, while in all other counties this indicator is lower.
- High investment costs due to the territory size and low population density in Lika-Senj County with an unfavorable economic structure are the reason for the estimated lowest benefit-cost ratio. On the other hand, the City of Zagreb, as a densely populated area, a relatively developed manufacturing industry and a centralized public administration, could achieve the most favorable benefit-cost ratio.

International comparison, the position of Croatian counties, the benefit-cost ratio

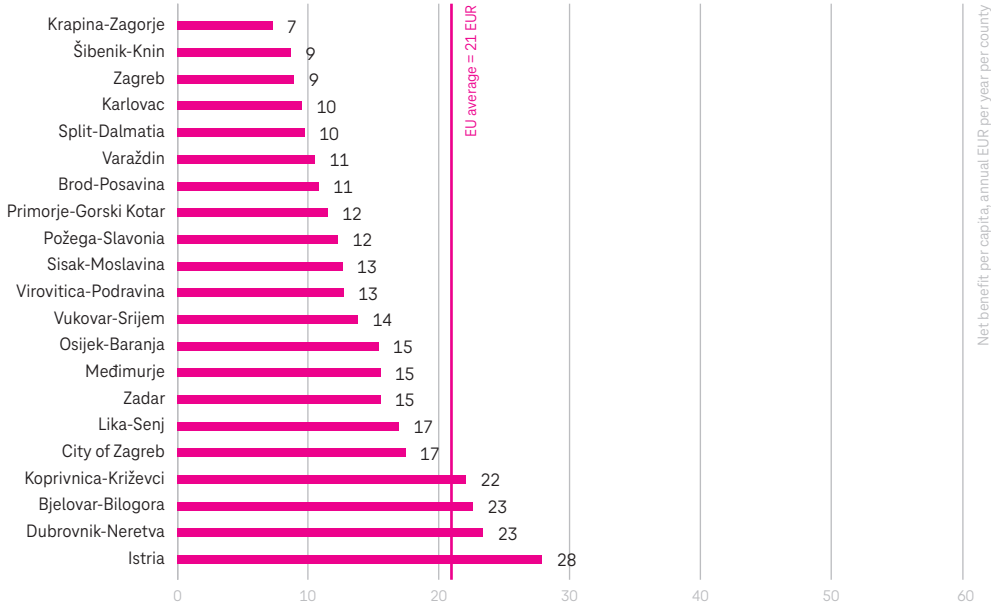


International comparison net benefits per capita

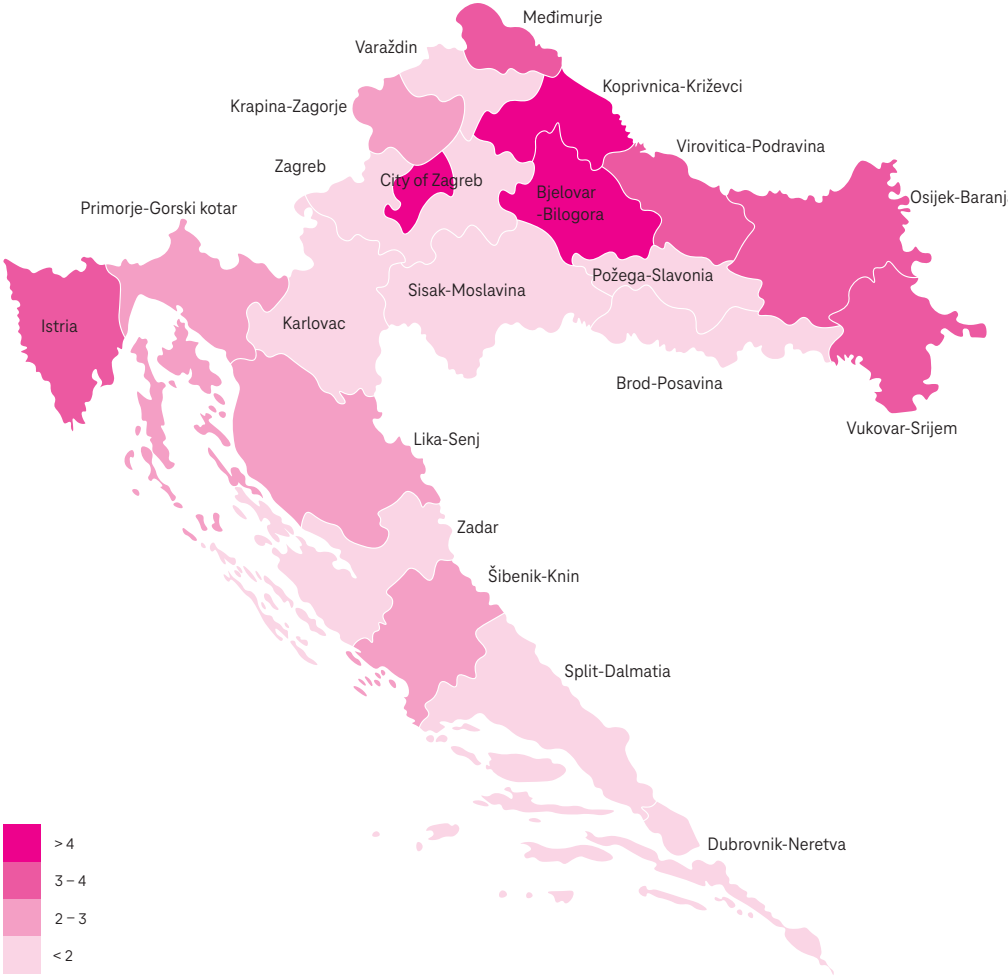


- In terms of expected net benefits per capita, Istria County could achieve an annual benefit of 28 EUR, which is above the average for EU countries and ranks it among the more developed countries, such as Germany.
- Only Dubrovnik-Neretva, Bjelovar-Bilogora, and Koprivnica-Križevci counties are above the EU average according to the expected net benefits per capita.
- According to this indicator, Šibenik-Knin and Krapina-Zagorje counties are at the bottom again with the expected benefits that are approximately similar to the EU countries where the lowest potential in terms of productivity growth is expected based on the application of 5G infrastructure.
- Among the EU countries, the group of least successful countries are Spain, Greece, Italy, Malta, and Portugal, for which the effects could be improved by exploiting the potential of the 5G network for tourism purposes.
- The 5G network enables every city and local community to apply the technology that is the foundation of social and economic development. Whether smart cities, digital agriculture, advanced medicine, education of the future or more efficient production, the 5G network is an indispensable part of every modern state and transformative business model due to its wide applicability and there is no sector or industry that will not have tangible benefits

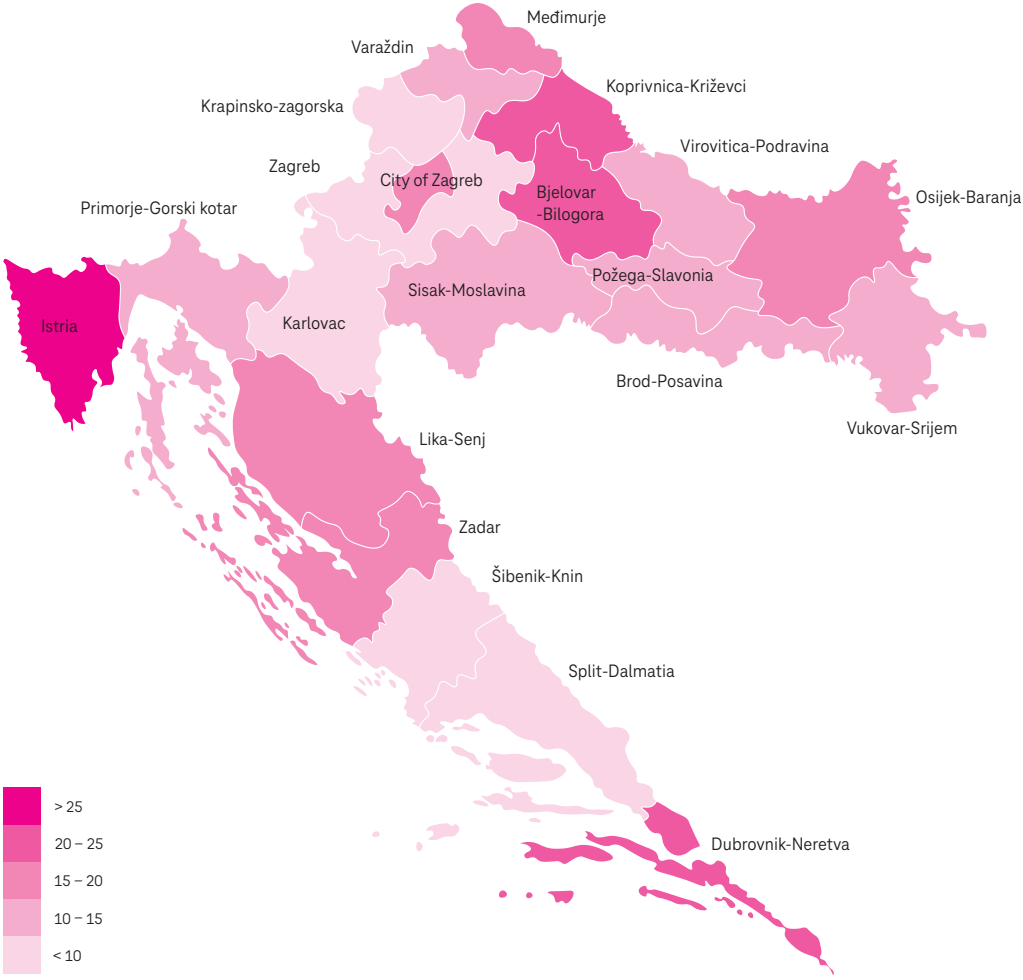
International comparison, position of Croatian counties, net benefit per capita



Benefit-cost ratio in the use of 5G network

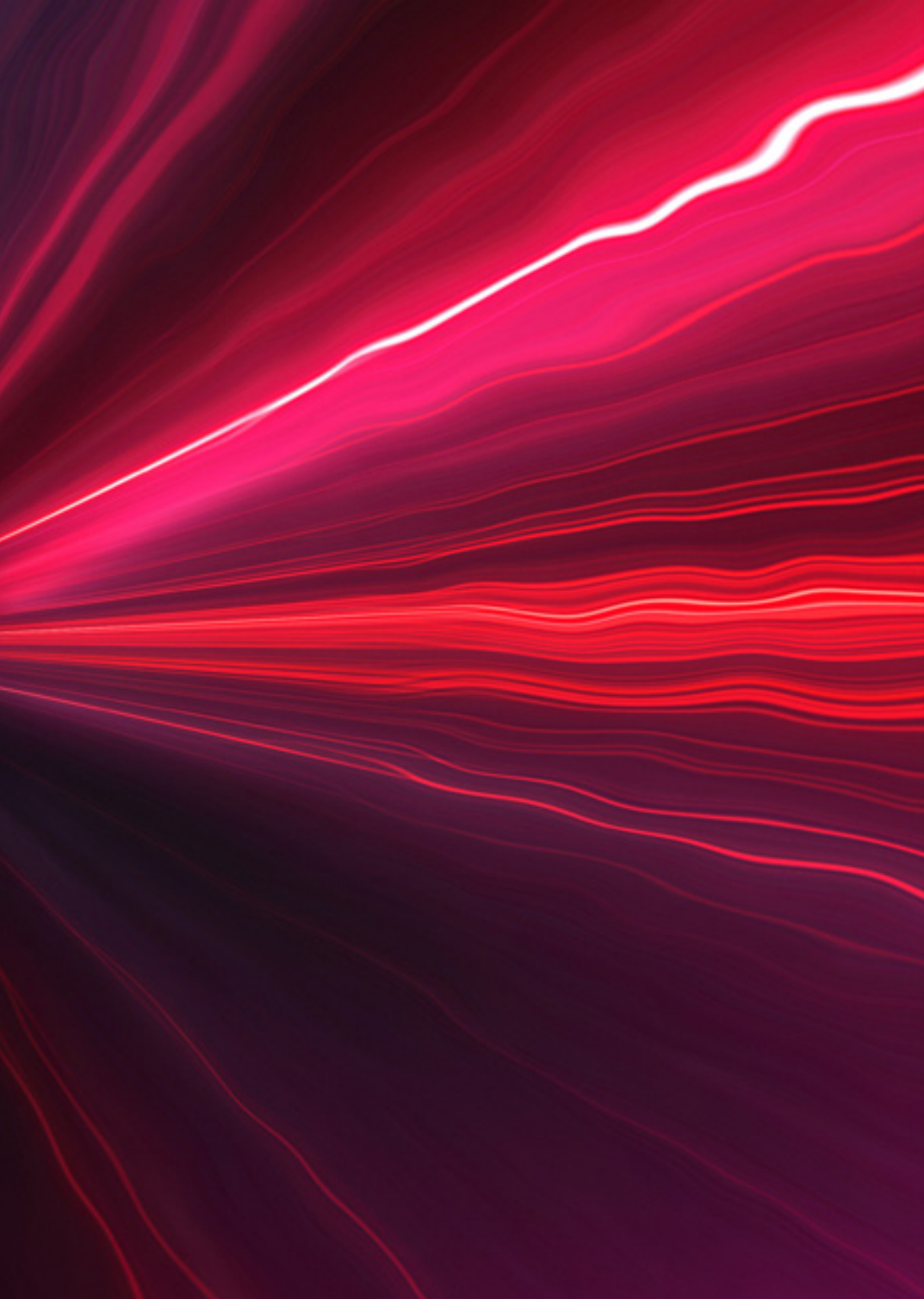


Net benefit per capita, EUR per year



4

Conclusion



The aim of this study was to assess the future economic benefits of developing 5G infrastructure and compare them with the expected costs of investing in the development of this infrastructure. For this purpose, potential benefits of the introduction of 5G infrastructure were assessed, and the costs of developing a 5G network were estimated for four economic clusters: Smart Manufacturing, Smart Rural, Smart Urban, and Smart Public Services for all counties in the Republic of Croatia, to determine the overall profitability and economic justification of investing in the development of 5G infrastructure.

The total benefits of investing in the 5G network expressed in terms of net present value in the Republic of Croatia are estimated at EUR 1.33 billion, three times more than the investment cost, which should amount to around EUR 445 million. The average benefit-cost ratio of investing in 5G infrastructure in the European Union is 4.3. Croatia is ranked 19th in the European Union with a ratio of 3.0 and can be classified in the group of countries that includes Estonia, Latvia, Greece, and Bulgaria, which has a comparable level of benefits. The annual net benefit per capita from investing in 5G infrastructure is EUR 14.5 per capita, while in terms of GDP the total net benefit from the development of 5G infrastructure is 1.72 percent of GDP. The largest amount of benefits with the most favorable benefit-cost ratio is expected in the Smart Rural cluster, where 4.3 times the amount of benefits is expected for each EUR of investment. In the Smart Manufacturing and Logistics cluster, benefits are expected in the amount of EUR 507 million, with the highest amount of required investments in infrastructure reaching EUR 228 million, so the benefit-cost ratio in this cluster is 2.2, which is lower than to the other three clusters. The biggest benefits from investing in 5G infrastructure in the Smart Manufacturing and Logistics cluster are expected for the manufacturing industry (EUR 256 million), tourism (EUR 222 million), while the benefits for airports and ports are estimated at EUR 19 and 10 million. A relatively high benefit-cost ratio is also expected in the Smart Public Services cluster, where an investment of EUR 10 million can generate 3.5 times higher benefits, while in the Smart Urban cluster investments of EUR 65 million can be expected, which can generate 2.7 times the amount used.

In addition to comparing the costs and benefits of developing 5G infrastructure, the study also analyzed the impact of increasing mobile speed

to a level that can be attributed to the 5G network on the operations of entrepreneurs. The results of this analysis suggest that the deployment of a 5G network at the national level could increase export sophistication by 10 percent while reducing operating costs by the same percentage. This would open the potential for up to three times higher share of new companies in the total population of business entities, which would significantly increase the currently stagnant market dynamism in the Croatian economy. The effects of the deployment of the 5G network can also be distinguished regarding the development of individual regions. In developed regions, the deployment of the 5G network has the potential to increase employment, sales, and export revenues. Such findings correspond to the existing structure of these regions. In less developed regions, the potential effects of the deployment of the 5G network will be reflected primarily in structural shifting as a precondition for achieving effects such as those identified in developed regions. Overall, the results of this analysis suggest that the deployment of 5G network has the potential to increase market dynamism, improve cost competitiveness, sophistication of the domestic economy, increase employment and revenues of entrepreneurs and lead to redistributive effects of economic activity among Croatian regions.

However, it should be noted that both analyzes use relatively conservative initial assumptions, which means that the economic effect estimates of 5G network development presented in this study are not final and probably represent the lower limit of overall economic benefits from 5G infrastructure development.

When interpreting the results of the analyses, it should be borne in mind that the temporal dynamics of the spread of effects is likely to be uneven. Once the 5G infrastructure is installed and ready for operation, some time is required for adaptation and industrial transformation, which will be followed by a rapid increase in the benefits of 5G infrastructure until the moment when technologies using 5G infrastructure are widespread in the activities of all economic clusters. With this maturity, room for further accelerated growth of benefits is decreasing, so the curve of expected benefits is s-shaped.

Furthermore, there is always a wide range of uncertainties in long-term estimates, especially when it comes to smaller territorial units, which

should be kept in mind when interpreting the results of the assessments in this study. The entry or exit of only one large company from a region can significantly affect the total gross value added and employment of a particular county. So far, the Croatian economy has lagged behind the more advanced EU members in terms of technological progress and the speed of economic transformation. The continuation of such trends would result in less intensive economic effects of using the 5G network. The actual effects, for the global and for the Croatian economy alike, may differ significantly from the estimates, may differ significantly from the estimates, depending on the currently unknown technological, social, and other processes that will take place in the future. The real effects depend on the way of defining and implementing public policy measures and on the success of policymakers and entrepreneurs to enable the timely quality digital transformation of the economy and the realization of the highest possible level of economic benefits.

The 5G-based economy will also introduce a new level of complexity into the policymaking and implementation and the regulation of social and economic processes. Namely, as 5G technologies increasingly permeate individual industries, new business models will emerge, while old methods of manufacture and delivery of goods and services will be either significantly changed or completely abandoned. These changes will require the adjustment and modernization of regulatory activities and public policies to make countries ready to live and do business in a 5G environment. In this regard, special emphasis will be placed on the adjustments that will need to be made in the regulation of cyber security, privacy, spectrum allocation, certification and standardization, education, health, and public infrastructure. The future ubiquity of 5G is a huge challenge for policy makers from today's perspective, as they must be prepared to regulate the widespread presence of 5G in everyday life and business, without creating a regulatory environment that limits ongoing private investment and innovation that will be crucial for the success of the 5G economy.

While in the 20th century public investment in physical infrastructure was the driving force of economic transformation and growth, in the 21st century private investment in technology has largely determined the way goods and services are produced and delivered. It is certain that private investment will keep this role in the future, which will lead to further transfor-

mation of the national and global economy. Therefore, optimally defined public policies, especially those related to the protection of intellectual property and policies that enable entrepreneurs to take risks, invest, and innovate will be key to fully realize the benefits of developing 5G infrastructure in the future.

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