



ASSESSMENT OF THE ECONOMIC VALUE OF THE 6 GHz SPECTRUM BAND IN INDIA

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EXECUTIVE SUMMARY

The Department of Telecommunications (DoT) of India is considering different approaches to open the 5925-7125 MHz spectrum frequency band (the “6 GHz band”) for license-exempt use. In this context, the purpose of this study is to provide an assessment of the economic value to be generated by each of the three potential alternatives.

The first alternative estimates the value of opening the entire 6 GHz band for Wi-Fi use. Under this option, our assessment considers two economic value areas: (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline” estimate), and (ii) the value of allocating the entire 1200 MHz of the 6 GHz band for Wi-Fi use. The second alternative estimates the economic value if the 6 GHz band were to be split for use between Wi-Fi and International Mobile Telecommunication (IMT) operators, allocating the lower 500 MHz of the 6 GHz band to Wi-Fi, and the upper 700 MHz of the band for use by telecommunication service providers. In comparison with the first alternative, this option values: (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline” estimate), and (ii) the value of allocating 500 MHz of the 6 GHz band for Wi-Fi use. In addition, to allow an “apples to apples” comparison with the first option, the analysis includes an assessment of the value to be generated through an auction of the upper part of the 6 GHz band to be used by IMT operators in 5G and 6G. The third alternative to be assessed, is a particular case of the second option: rather than allocating 700 MHz to IMT, it allocates only 100 MHz, thereby allowing WI-FI devices to use 1100 MHz of the 6 GHz band. As in the prior case, this option would also enable a new auction for development of 5G and 6G, although in this case the amount of spectrum available would be only 100 MHz.

The methodology used to develop estimates for the three alternatives is similar to the one used in prior studies conducted by the authors, whereby the different sources of economic value are estimated independently, and then aggregated within a single value (this allows cumulating GDP impact, with consumer and producer surplus¹) (see table A).

¹ We consider that combining GDP effect and producer surplus on equipment sales is reasonable given that the impact on GDP is fundamentally attributed in our models based on historical data to speed increase and not to produce surplus driven by equipment sales triggered by new unlicensed spectrum allocation. On the other hand, CAPEX savings incurred by wireless carriers incurred by offloading traffic to Wi-Fi has been occurring for a while and could also be included in the GDP model estimates.

Table A. Sources of economic value of Wi-Fi to be assessed

Source	Effects	Consumer Surplus	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	X		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			X
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7	X		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	X		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	X		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	X		
	2.2. Avoidance of inside wiring investment	X		
	2.3. Consumer benefit derived from faster broadband speed	X		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	X		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			X
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		X	
	3.2. Avoidance of enterprise building inside wiring		X	
	3.3. Benefits derived from an increase in average speed			X
	3.4. Benefits derived from reduced latency			X
	3.5. Enhanced IoT deployment			X
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			X
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		X	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			X
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			X
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		X	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		X	
	5.3. Benefits of Firms in the IoT ecosystem		X	
	5.4. Benefits of firms in the AR/VR ecosystem		X	

Source: Telecom Advisory Services analysis

The economic contribution of each of the three alternatives for India is presented below.

Economic value of allocating the full 6 GHz band for Wi-Fi

The cumulative economic value between 2024 and 2034 for the first alternative (baseline scenario plus allocating the full 6 GHz band for unlicensed use) amounts to US\$ 4,030 billion², comprising US\$ 3,544 billion in GDP contribution, US\$ 158 billion in producer surplus and US\$ 329 billion in consumer surplus (see table B).

² All value estimates and calculations in this report are presented in United States dollars.

Table B. India: Economic value of Wi-Fi in case of full allocation of 6 GHz band for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Surplus	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 329,353
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7	\$ 2,828		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 19,141		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,824		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 159,698
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 16,565	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 993,114
	3.4. Benefits derived from reduced latency			\$ 1,277,606
	3.5. Enhanced IoT deployment			\$ 772,904
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 9,007
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 7,911	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 809
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,128
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,707	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,652	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 115,933	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 5,480	
TOTAL (in US\$ billion)		\$ 328.7	\$ 157.7	\$ 3,543.6

Source: Telecom Advisory Services analysis

Economic value of Wi-Fi if the lower 500 MHz is allocated for Wi-Fi and the upper 700 MHz for use by IMT

The allocation on only 500 MHz rather than 1200 MHz of the 6 GHz band has significant implications on WI-FI performance and, consequently, its economic value. As an example:

- The total number of devices that a Wi-Fi hotspot site can support simultaneously depends on the allocated bandwidth, the usage and traffic demand profile of the average user and the simultaneity factor which depends on the number of devices connected at the same time. Considering wireless internet usage statistics for India, the

number of users that can be handled by a free hotspot under the 500 MHz frequency allocation will be reduced by 41.18% relative to allocating the full 1200 MHz.³

- Within a residential use, if the frequencies allocated for unlicensed use in the 6 GHz band are reduced from 1200 MHz to 500 MHz, this has an impact on the number of resource units assigned for transmission, and consequently the maximum speed at the device level.
- The increase in subscribers that can be handled by Wireless ISPs relying on Wi-Fi technology depends on the number of outdoor channels. Considering that the 500 MHz alternative supports 25 20 MHz channels, compared to 42 under the full 6 GHz band, the maximum number of users with 242 Resource Units decreases by 40.48%
- An allocation of 500 MHz of the 6 GHz band rather than 1200 MHz would decrease the number of IoT sensors that can be connected by 58.33%.
- A simulation of AR/VR use in a school setting indicates that when considering a 1200 MHz allocation of the 6 GHz band, Wi-Fi can support 22 headsets; the number of headsets diminishes to 4 if only 500 MHz spectrum is allocated in the same band.

The effects discussed above, and other ones analyzed in this study have a significant effect on Wi-Fi economic value. The cumulative economic value for the second alternative (baseline scenario plus allocating 500 MHz for unlicensed use) for the 2024-2034 period amounts to US\$ 2,918 billion, composed of US\$ 2,513 billion in GDP contribution, US\$ 84 billion in producer surplus and US\$ 321 billion in consumer surplus (see table C).

³ All engineering calculations are presented in Appendices B and C.

Table C. India: Economic value of Wi-Fi in case of allocating 500 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Surplus	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 270,620
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7	\$ 1,663		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 13,607		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,071		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 138,060
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 14,686	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 611,572
	3.4. Benefits derived from reduced latency			\$ 1,124,392
	3.5. Enhanced IoT deployment			\$ 363,605
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 3,119
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 1,342	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 667
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,037
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,282	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,308	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 54,144	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 2,449	
TOTAL (in US\$ billion)		\$ 321.3	\$ 83.6	\$ 2,513.1

Source: Telecom Advisory Services analysis

The decrease in economic value from the first alternative (amounting to US\$ 1,112 billion) is due to the following effects:

- 40.48% of Wi-Fi outdoor accessibility provided by WISPs is limited due to their access points restricted access to the 6GHz band.
- Wi-Fi indoor speed is restricted by 50%, which means that residential broadband access undergoes a bottleneck for lines in excess of 600 Mbps.
- Under a constant speed assumption, latency would increase under frequency allocation scenarios: in other words, the 500 MHz alternative would result in a lower reduction of latency relative to the 1200 MHz option.
- More than half of IoT devices undergoes a limit in their indoor and outdoor access.

- 81.82% of the AR/VR devices supported in indoor environments is restricted by limits in terms of their ability to operate.

Part of the negative economic impact of limiting access of the 6 GHz band for Wi-Fi is mitigated by the benefits resulting from allocating 700 MHz to be auctioned for use by IMT. Revenues to be collected amount to US\$ 254 billion.

- The GSMA estimates that the allocation of mid bands to IMT in Asia and Pacific would generate a GDP contribution of US\$ 285 billion in 2030, from where US\$ 30 billion can be interpolated for India.⁴ Prorating this value to the 700 MHz in the 6 GHz band yields a total GDP contribution between 2024 and 2034 of US\$ 83 billion.
- Additionally, by gaining access to 700 MHz, wireless service providers could generate US\$ 26 billion in producer surplus (primarily driven by IoT deployment) and US\$ 139 billion in consumer surplus.
- Finally, it is estimated that auction proceeds for 700 MHz in the 6 GHz band could generate US\$ 6 billion.

Considering the economic value associated with the 6 GHz band only (therefore excluding the baseline effect), the total economic benefits between 2024 and 2034 of allocating the lower 500 MHz for unlicensed use and the upper 700 MHz band for use by IMT is US\$ 2,248 billion, of which US\$ 1,994 billion is generated by the spectrum received for unlicensed use and US\$ 254 billion would be generated by IMT.

Economic value of Wi-Fi if the lower 1100 MHz is allocated for unlicensed use and the upper 100 MHz for use by IMT

While the economic value of this alternative is higher than allocating 500 MHz to Wi-Fi, it still denotes some decrease from allocating the full band:

- Considering internet usage statistics for India, the number of users that can be handled by a free hotspot under 1100 MHz frequency allocation will be reduced by 5.88% from the 1200 MHz alternative.
- The increase in subscribers that can be handled by Wireless ISPs relying on Wi-Fi technology depends on the number of outdoor channels. Considering that a 1100 MHz alternative supports fewer channels compared to 42 under the full 6 GHz band, the maximum number of users with 242 Resource Units decreases 4.76%.
- An allocation of 1100 MHz of the 6 GHz band rather than 1200 MHz would decrease the number of IoT sensors that can be connected by 8.33%.
- A simulation of AR/VR use in a school setting indicates that when considering a 1200 MHz allocation of the 6 GHz band, Wi-Fi can support 22 headsets; the number of headsets diminishes by 60% if only 1100 MHz spectrum is allocated in the same band.

These effects discussed and other ones analyzed in this study still have an effect on Wi-Fi economic value. The cumulative economic value of Wi-Fi for the 2024-2034 period driven by the third alternative (baseline scenario plus 1100 MHz spectrum allocated to Wi-Fi) amounts to US\$ 3,943 billion, composed of US\$ 3,469 billion in GDP contribution, US\$ 146 billion in producer surplus and US\$ 329 billion in consumer surplus (see table D).

⁴ Source: GSMA, "The Socio-Economic Benefits of Mid-Band 5G Services" (February 2022)

Table D. India: Economic value of Wi-Fi in case of allocating 1100 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Surplus	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 320,967
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7	\$ 2,661		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 19,141		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,824		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 157,154
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 16,565	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 993,114
	3.4. Benefits derived from reduced latency			\$ 1,277,606
	3.5. Enhanced IoT deployment			\$ 714,453
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 3,892
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 6,889	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 809
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,117
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,707	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,652	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 107,109	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 3,257	
TOTAL (in US\$ billion)		\$ 328.5	\$ 145.6	\$ 3,469.1

Source: Telecom Advisory Services analysis

In this case, there is also a decrease in economic value with respect to the first alternative (US\$ 87 billion). As expected, the allocation of 100 MHz for IMT will mitigate part of the value reduction in comparison with the first alternative by generating revenues amounting to US\$ 41 billion:

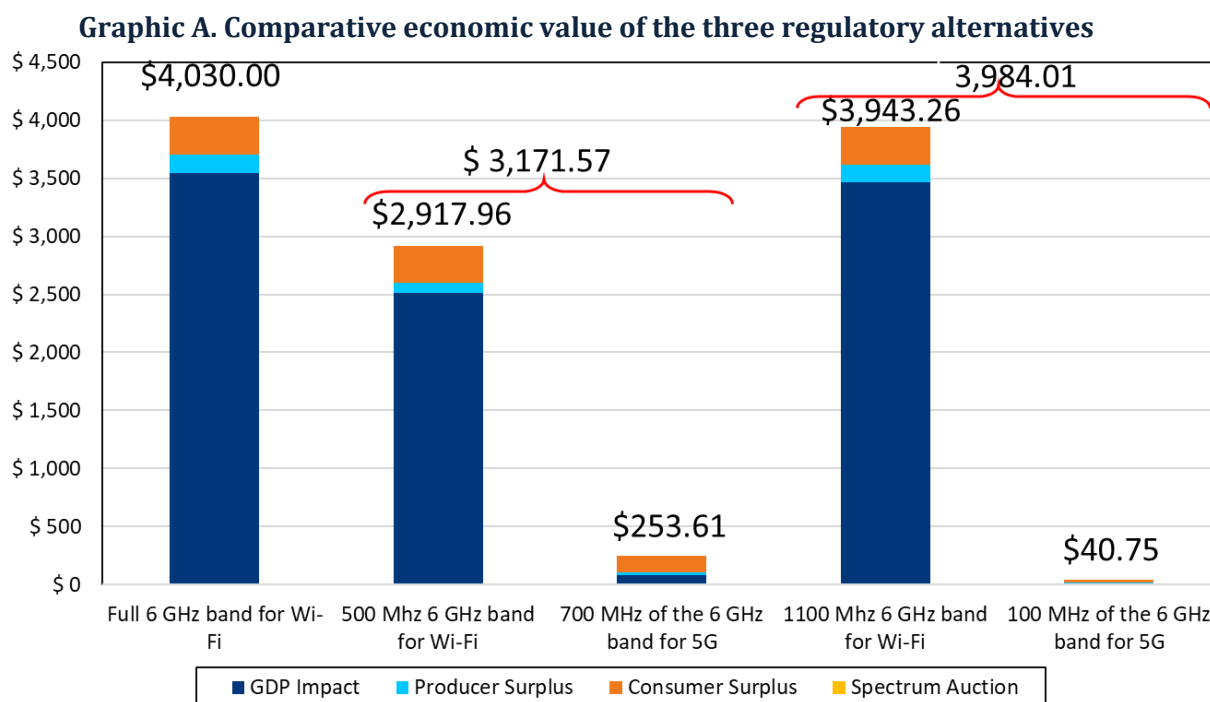
- Prorating the GDP contribution estimated by GSMA to the case of 100 MHz in the 6 GHz band yields a total GDP contribution between 2024 and 2034 of US\$ 12 billion.
- Additionally, by gaining access to 100 MHz, wireless service providers could generate US\$ 4 billion in producer surplus (primarily driven by IoT deployment) and US\$ 24 billion in consumer surplus.
- Finally, it is estimated that auction proceeds for 100 MHz in the 6 GHz band could generate US\$ 1 billion.

Considering the economic value associated with the 6 GHz band only, the total economic benefits between 2024 and 2034 of allocating the lower 1100 MHz for unlicensed use and the

upper 100 MHz band for use by IMT is US\$ 3,060 billion, of which US\$ 3,019 billion is generated by the spectrum received for unlicensed use and US\$ 41 billion would be generated by IMT.

Conclusion and implications

A comparison of the three regulatory alternatives indicates that the highest economic impact is associated with the full allocation of the 6 GHz band for use by Wi-Fi (see Graphic A).



Source: Telecom Advisory Services analysis

As indicated in graphic A, the full allocation to Wi-Fi is US\$ 46 billion higher than the third alternative estimated, and US\$ 858 billion than the second one. These advantages occur, even considering revenues collected from spectrum auctions, and without considering the costs to IMT generated by spectrum refarming. In summary, the allocation of the 1200 MHz of the 6 GHz will generate the highest economic value for India, which becomes the most attractive alternative of the three under consideration.

A final consideration needs to be made. Assuming that the World Radio Conference decides in WRC-27 to allocate the upper 6 GHz band to IMT, then equipment and devices for wideband mobile networks would still need to be designed, tested and deployed. Furthermore, auctioning the upper 6 GHz band can only be done after WRC 2027. Under this scenario, it would take another two years to reach useful deployment of service. Alternatively, Wi-Fi technology, equipment and devices are available globally and can be deployed immediately, with no additional allocation requirements. Under these considerations, extending the timeline to allocate the upper portion of the band to IMT has an opportunity cost implication, since any economic value will not be generated until 2029. Similarly, if India delays making any decision on the 6 GHz band and waits until the upper 6 GHz is sorted out in WRC 27, the contribution to the economy due to “no decision taken” will be equally affected.

1. INTRODUCTION

The Department of Telecommunications of India (DoT) is considering different approaches to open the 5925-7125 MHz spectrum frequency band (the “6 GHz band”) for license-exempt use. The purpose of this study is to provide an assessment of the economic value of the 6 GHz band under three alternatives:

- An assessment of the value of opening the entire 6 GHz band for Wi-Fi. This assessment considers two economic value areas: (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline”), and (ii) the value of allocating the entire 1200 MHz of the 6 GHz band for Wi-Fi use.
- An estimation of the economic value if the 6 GHz band were to be split between Wi-Fi and International Mobile Telecommunication (IMT), allocating the lower 500 MHz for Wi-Fi, as is currently the case, and the upper 700 MHz band for use by telecommunication service providers. In comparison with the first alternative, this option values: (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline”), and (ii) the value of allocating 500 MHz of the 6 GHz band for Wi-Fi use. In addition, to allow an “apples to apples” comparison, this option includes an assessment of the value to be captured through an auction of the upper part of the 6 GHz band to be used by mobile service providers for 5G and 6G.
- The third alternative represents a particular case of the second option: rather than 700 MHz, it allocates only 100 MHz to IMT, thereby allowing Wi-Fi devices to use 1100 MHz on the 6 GHz band. As in the prior alternative, this option would also require holding a new auction for development of 5G and 6G, although in this case the amount of spectrum would be 100 MHz.

The time horizon for quantifying economic value of the three alternatives is 2024-2034. At the aggregate level, the methodology relied upon in this study is exactly the same as the one used in our prior studies⁵, whereby the different sources of economic value are estimated independently and then aggregated within a single value (this allows cumulating GDP impact, with consumer and producer surplus).

Chapter 2 presents the theoretical framework to be used in the assessment of the three allocation alternatives described above. Chapter 3 estimates the economic benefits of allocating the 1,200 MHz for its use by Wi-Fi. Chapter 4 shifts the focus to the economic implications of dedicating the lower 500 MHz of the band to Wi-Fi use, reiterating similar benefits as discussed in Chapter 4 but within the context of this narrower allocation. In addition, it quantifies the economic value of allocating the upper 700 MHz to the IMT players. Chapter 5 quantifies the value of the alternative that restricts the IMT allocation to 100 MHz, with rest of the 6 GHz band being allowed for unlicensed use. Finally, Chapter 6 concludes by summarizing the total economic value generated by the three 6 GHz allocation alternatives and drawing the policy implications.

⁵ Katz, R. (2014). *Assessment of the economic value of unlicensed spectrum in the United States*. New York: Telecom Advisory Services; Katz, R. (2014). *Assessment of the future economic value of unlicensed spectrum in the United States*. New York: Telecom Advisory Services; Katz, R. (2020). *Assessing the economic value of unlicensed use in the 5.9 GHz and 6 GHz bands*. Washington, DC: Wi-Fi Forward. Katz, R., Jung, J. and Callorda, F. (2021). *The Economic value of Wi-Fi: A Global View (2021 and 2025): A report for the Wi-Fi Alliance*. New York: Telecom Advisory Services. October. Katz, R., Jung, J., Callorda, F. and Valencia, R. (2024). *An assessment of Wi-Fi economic value in the United States*. New York: Telecom Advisory Services.

2. STUDY THEORETICAL FRAMEWORK AND METHODOLOGIES FOR ESTIMATING THE ECONOMIC VALUE OF THE 6 GHz BAND

The allocation of the 6 GHz band for unlicensed use by Wi-Fi devices yields economic value by complementing wireline and cellular wideband technologies, thereby enabling the development of products and services that enlarge consumer choice, support the creation of innovative business models, and expand access to communications. The following chapter begins by defining the intrinsic value of the unlicensed use of the 6 GHz band, both as a complementary to the telecommunications ecosystem, by enhancing the performance of networks, and providing a platform for developing innovative applications. Following this, we put forward the concept of economic value, calculated as gains to consumer and producer surplus, and a contribution to GDP. Having formalized these sources of value, we then move to categorize the five economic agents that benefit from them: (i) individual consumers benefitting from access to free Wi-Fi service, (ii) individual consumer residences, (iii) enterprises, (iv) Internet Service Providers, and (v) manufacturers of communications equipment and consumer electronics. This categorization provides the framework for defining spectrum allocation assumptions and methodologies to assessing different alternatives.

2.1. The intrinsic value of unlicensed spectrum

Considered as a factor of production, a complementary technology is a resource that, due to its intrinsic strengths, compensates for the limitations of another resource. Complementarity has been initially studied as the interdependencies supporting the stimulation of demand of capital goods. This effect operates in the technology sector at two levels: (i) a given technology enables the production of another one by lowering manufacturing and distribution costs (Dosi et al., 1990; Schmookler, 1966), and/or (ii) one technology addresses bottlenecks in the diffusion and adoption of a second one (Rosenberg, 1976). The first level focusses on reducing the cost of intermediate inputs, while the second one addresses user needs.

The study of technology interdependencies has been extended to address the complementarity within value chains (Mäkitie et al., 2022). The authors analyze three mechanisms by which complementarity emerges: (i) **synchronization**, which depicts “the simultaneous and mutually supporting development between the input and user sectors in a technology value chain”; (ii) **amplification**, where a technology accelerates the adoption of another one; and (iii) **integration**, whereby technological advances in one sector spill in accelerating the development and adoption of technology in another one. In particular, the principle of “amplification” is defined as follows:

“Diffusion of a novel technology in a user sector creates demand for products and services in the input sectors of the [technology value chain], making it imperative that input sectors are scalable enough to ensure a balance between supply and demand. Thus, economies of scale may emerge, driving further development and deployment in the user sector due to reduced costs, network effects, and increased availability of necessary services and products.” (p.9)

The complementarity between devices and technologies, relying on unlicensed spectrum and wideband networks, appears to be a clear example of amplification. Each technology was developed independently, although their combination acts as a multiplier of demand and impact. For example, Wi-Fi can enhance the effectiveness of devices, such as smartphones, which typically rely on licensed spectrum. Wi-Fi access points can enhance the value of cellular

networks by allowing wireless devices to switch to Wi-Fi hotspots, thereby relieving the burden on the mobile wireless network, - reducing the cost of broadband access and increasing the access speed rate. Consumers accessing the Internet within the reach of a Wi-Fi access point can also reduce their access costs by turning off their cellular service. They can also gain additional access speed as the transfer data rate of Wi-Fi sites is generally faster than that offered by current cellular technology.⁶ Likewise, many wireless operators reduce their capital spending by complementing their cellular networks with carrier-grade Wi-Fi access points, which are considerably less expensive than cellular network equipment with similar capacity.⁷ In addition to reducing capital expenditures, wireless carriers can offer fast access to service without a base station congestion challenge.

Furthermore, Wi-Fi can provide the required environment to enable the development and introduction of innovations such as Wi-Fi-enabled communications devices, wireless security systems and household appliances, thereby providing consumers with a larger set of choices. By limiting transmission power and relying on spectrum with low propagation, Wi-Fi avoids interference, rendering irrelevant any barriers to innovation caused by the need to use licensed spectrum. In fact, some of the most important technological innovations in communications are intimately linked to Wi-Fi for gaining access. Numerous products and services, such as the multi-AP/mesh networking systems and smart speakers launched in the past were developed leveraging Wi-Fi. By providing consumers with service choices in addition to those offered through cellular services, Wi-Fi also supports the development of innovative business models. Firms developing new applications that rely on Wi-Fi do not need approval from cellular operators, do not incur time-to-market penalties, and do not face financial disincentives derived from costly revenue splits with cellular service providers.

In addition to innovative applications, technologies relying on unlicensed spectrum used by Wi-Fi technology can help address the digital divide in broadband coverage. A portion of the population that has not adopted broadband access is located in rural and isolated areas. Many of them can gain access to the Internet through free Wi-Fi service offered by anchor public institutions such as libraries, municipalities or supplied for a fee by Wireless Internet Service Providers (WISPs), which typically provide end-connectivity to consumer devices through Wi-Fi.

2.2. The derived value of unlicensed spectrum

There is a significant amount of research-based evidence demonstrating that unlicensed spectrum technology has very high social and economic value. At a highest level, contrary to licensed bands where economic value can equate to whatever is paid at auction, the economic value of unlicensed spectrum, such as Wi-Fi, needs to be measured based on the concept of economic surplus.⁸

⁶ For example, at the end of 2023 the average mobile connection speed in the United States is estimated by Ookla at 208 Mbps while the average Wi-Fi speed is 289 Mbps (Source: data extracted from Ookla Speedtest.net).

⁷ The CAPEX savings resulting from Wi-Fi offloading for a cellular carrier in 1.5 million population cities is approximately 30 percent (Source: LCC Wireless). See also Spirent. *Wi-Fi Offload: Is your gateway ready?* Retrieved in: https://assets.ctfassets.net/wcxs9ap8i19s/0CmCW0buQpAINDJKN2z9NJ/b860733ac8cc6b724a55080b89f1cc60/WiFi_Offload_Whitepaper.pdf; ENEA. The drivers for Wi-Fi offloading. Retrieved in: <https://www.enea.com/insights/the-drivers-for-wifi-offloading/>

⁸ Thanki, R. (2009); Thanki, R. (2012). *The Economic Significance of License- Exempt Spectrum to the Future of the Internet*. London; Perspective Associates; Milgrom, P., et al. (2011); Katz, R. (2014).

The concept of economic surplus is based on the difference between the value of units consumed and produced up to the equilibrium price and quantity, allowing for the estimation of consumer surplus and producer surplus.⁹ Consumer surplus measures the total amount consumers would be willing to pay to have the service, compared to what they actually pay. Producer surplus measures the analogous quantity for producers, which is essentially the economic profit they earn from providing the service. Consumer and producer surplus together yield an economic surplus. Adding GDP contribution results in a total economic value estimate.

Consistent with the concept presented above, this study measures the economic value of the 6 GHz band by focusing first on the economic surplus generated after its adoption.¹⁰ The underlying assumption is that unlicensed spectrum technologies such as Wi-Fi generate a shift both in the demand and supply curves, resulting from changes in how services are produced, as well as the corresponding willingness-to-pay for such services. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is, as mentioned above, whether Wi-Fi represents a positive contribution to wireless carriers' capital expenditures (CAPEX) and operating expenses (OPEX) insofar as they can control their spending, while meeting demand for increased wireless traffic. From an economic theory standpoint, the telecommunications industry can then increase its output, yielding a marginal benefit exceeding the marginal cost. This results in a shift in the supply curve by a modification in the production costs. The shift in the supply curve yields a new equilibrium price and quantity. Additionally, since the demand curve is derived from the utility function¹¹, the consumer surplus from stable Wi-Fi prices, yields an increase in the willingness-to-pay, and consequently a drives shift in the demand curve. Under these conditions, total economic value is now represented by both changes in the consumer and producer surplus.

To quantify the incremental surplus derived from Wi-Fi technology adoption, we need to itemize all the effects linked to this technology. In addition, we complement the concept of economic surplus with an assessment of the direct contribution of the technologies and applications relying on Wi-Fi to national GDP. By including the GDP contribution measurement, we follow Greenstein et al. (2010) and prior research literature measuring the economic gains of new goods.¹² We focus on consumer and producer surplus, but also consider the new economic growth enabled by Wi-Fi. In measuring the direct contribution to GDP, we strictly consider the revenues added "above and beyond" what would have occurred had the Wi-Fi spectrum been licensed. After quantifying Wi-Fi's contribution to GDP, the impact on job

⁹ Following Alston (1990), we acknowledge that this approach ignores effects of changes in other product and factor markets; for example, Wi-Fi also increases the economic value of technologies operating in licensed bands (Alston, J.M. and Wohlgenant, M.K. (1990). "Measuring Research Benefits Using Linear Elasticity Equilibrium Displacement Models". John D. Mullen and Julian M. Alston, *The Returns to Australian Wool Industry from Investment in R&D*, Sydney, Australia: New South Wales Department of Agriculture and Fisheries, Division of Rural and Resource Economics).

¹⁰ See a similar approach used by Mensah and Wohlgenant (2010) to estimate the economic surplus of adoption of soybean technology (Mensah, E., and Wohlgenant, M. (2010). "A market impact analysis of Soybean Technology Adoption", *Research in Business and Economics Journal*).

¹¹ A utility function measures the consumer preference for a service beyond the explicit monetary value paid for it.

¹² Greenstein, S. and McDevitt, R. (2009). *The broadband bonus: accounting for broadband Internet's impact on U.S. GDP*. National Bureau of Economic Research Working Paper 14758. Cambridge, MA.

creation can also be ascertained not only within the telecommunications industry but also in terms of the spillovers through the rest of the economy.

2.3. Sources and economic agents driving value of unlicensed spectrum

The economic value of unlicensed spectrum is generated from multiple sources of value, including (i) the capability to deliver traffic at faster speed and lower latency than other networking technologies, (ii) provide Internet access, and (iii) interconnect devices. These sources of economic value are then channelled into economic gains for five economic agents:

- Individual consumers accessing free Wi-Fi sites.
- Residential consumers.
- Enterprises.
- Internet service Providers (ISPs); and
- Companies that provide Wi-Fi products and services or manufacture products enabled by Wi-Fi (participants in the Wi-Fi ecosystem).

For each economic agent, the above-mentioned sources of value translate into cost savings, productivity gains, and expanded economic activity:

- **Free Wi-Fi:** The providers of free Wi-Fi service (i.e., coffee shops, retailers, municipalities, public libraries) allow consumers to connect to the Internet without paying for access, creating a surplus to consumers.¹³ Additionally, free Wi-Fi hotspots could also provide Internet access to those consumers that lack broadband service, thereby partially bridging the “digital divide”. While less important in metropolitan areas, this effect could be critical to increasing broadband adoption in some less developed geographies, and hence, convey impact on GDP.¹⁴
- **Residential Wi-Fi:** Residential Wi-Fi also drives consumer surplus. Routers installed in home dwellings provide Internet access for devices that lack a wired port (i.e., tablets, smartphones, netbooks), allowing consumers to avoid the investment in Ethernet

¹³ This category does not include providers of paid Wi-Fi access such as those operating in airports or hotels; this type of agent is included in the Internet Systems Providers category below.

¹⁴ See Katz, R., & Jung, J. (2021). *The economic impact of broadband and digitization through the COVID-19 pandemic – Econometric modelling* (ITU report). International Telecommunication Union. Available at: https://www.itu.int/pub/D-PREF-EF.COV_ECO_IMPACT_B-2021. Barrero, J. M., Bloom, N., & Davis, S. J. (2021a). Internet access and its implications for productivity, inequality, and resilience. In M. S. Kearney & A. Ganz (Eds.), *Rebuilding the post-pandemic economy*. Aspen Institute Press. Retrieved in: <https://www.economicstrategygroup.org/publication/barrero-bloom-davis/> Bertschek, I., Briglauer, W., Hüschelrath, K., Kauf, B., & Niebel, T. (2015). “The Economic Impacts of Broadband Internet: A Survey.” *Review of Network Economics*, 14(4), 201–227. Retrieved in: <https://doi.org/10.1515/rne-2016-0032>; De Clercq, M., D’Haese, M., & Buyse, J. (2023). “Economic growth and broadband access: The European urban-rural digital divide.” *Telecommunications Policy*, 47(6), Article 102579. <https://doi.org/10.1016/j.telpol.2023.102579>; Isley, C., & Low, S. A. (2022). “Broadband adoption and availability: Impacts on rural employment during Covid-19.” *Telecommunications Policy*, 46(7), Article 102310. <https://doi.org/10.1016/j.telpol.2022.102310> ; Katz, R., & Jung, J. (2022a). *The contribution of fixed broadband to the economic growth of the United States between 2010 and 2020*. Telecom Advisory Services LLC.; Katz, R.; Jung, J. (2022b). “The Role of Broadband Infrastructure in Building Economic Resiliency in the United States during the COVID-19 Pandemic.” *Mathematics* 10, 2988. <https://doi.org/10.3390/math10162988>.

wiring.¹⁵ Wi-Fi routers also support easy networking between devices (printers, storage devices, computers), allow for sharing and streaming media content (sound systems, home theaters, etc.), represent a network hub to handle home automation, and may interface with a smart grid. Additional surplus is generated as a Wi-Fi connection for last mile of fixed broadband is typically faster than that of a cellular network.¹⁶ Finally, consumer surplus is generated if the willingness-to-pay exceeds the price paid for purchasing residential Wi-Fi devices and equipment. All of these effects can be aggregated in terms of the residential consumer surplus.

- Enterprise Wi-Fi:** Wi-Fi in office buildings and industrial campuses allows for voice and data communications without incurring the cost of “capped” connectivity and avoids the limited in-building coverage of cellular networks, as well as the cost of enterprise wiring. Additionally, Wi-Fi supports communication between enterprises and their customers (i.e., customer/client access in financial services, employee/guest connections in the hospitality industry), while also improving internal production efficiencies (product/inventory tracking, remote control equipment, and POS ordering in the retail industry). This equates to a producer surplus, composed of the cost savings enjoyed by enterprises that rely on Wi-Fi technology, rather than wideband cellular service. In addition, Wi-Fi allows faster access to the Internet than cellular networks do. These faster speeds have a positive contribution to the economy in terms of increased overall productivity, efficiency, and innovation. Finally, Wi-Fi technology facilitates the expansion of Internet of Things (IoT) platforms and Augmented Reality and Virtual Reality (AR/VR) applications. Those developments generate productivity spillovers on the economy, thereby contributing to the growth of GDP.
- Internet Service Providers (ISPs):** Due to the explosive growth in data traffic, wireless carriers operating in licensed bands deploy Wi-Fi access points to reduce both capital and operating expenses and reduce congestion challenges. Since ISPs monetize the Wi-Fi access they provide, the producer surplus measures the difference in capital and operating expenses for the traffic that is off-loaded. This model is critical to understanding Wi-Fi’s contribution to 5G deployment, yielding economic value generated for wireless carriers who offload 5G traffic on to Wi-Fi in the home/business. Wi-Fi allows service providers to launch paid Internet access in public places (such as venues, stadiums, airports, airlines, hotels, etc.). These access points generate new revenues that would not exist if Wi-Fi were not available. Similarly, Wireless Internet Service Providers (WISPs) rely on Wi-Fi to offer broadband connectivity in areas typically not served by wireline carriers, yielding additional revenues to be accounted for as part of the GDP. Since the technology allows for increasing broadband penetration, it becomes a key factor in driving service coverage and, consequently, GDP growth. This could have multiple positive effects, such as job creation, enhancing the productivity of rural businesses, and increasing access to public services.¹⁷
- Wi-Fi ecosystem:** Locally manufactured Wi-Fi devices generate revenues. The difference between the market price of these Wi-Fi enabled devices and the cost to

¹⁵ This effect is not total since users can potentially purchase adapters for smartphones and tablets, although the most popular connectors (such as micro-USB to Ethernet) cannot deliver comparable speeds and require some consumer inputs to be activated.

¹⁶ This effect is particularly important in 4G networks but could also be relevant in relation to indoor reception.

¹⁷ Katz, R. and Beltran, F. (2015). *Socio-economic impact of alternative spectrum assignment approaches*. Presentation to the International Telecommunications Society Regional Conference, Los Angeles, CA.

manufacture them represents the manufacturer's profit margin (producer surplus). Such products include home networking devices, Wi-Fi enabled wireless speakers, routers, and security systems on the consumer side, and access points and controllers on the enterprise side. Similarly, as Wi-Fi facilitates the expansion of IoT, developing firms within the IoT ecosystem (hardware, software, and services), it generates a producer surplus. Finally, the economic effect of AR/VR is driven in part by an ecosystem that includes firms ranging from software development to hardware production and applications development. The profit margins of firms involved in this endeavor represent again producer surplus.

2.4. Methodologies for estimating the economic value of unlicensed spectrum

Measuring the economic value of Wi-Fi requires a formal approach that can integrate the various economic gains, whether consumer or producer surplus, as well as their net direct contributions to the GDP.¹⁸ The methodology used in this study is structured around the surplus captured by each of the five economic agents reviewed above (individuals benefitting from free Wi-Fi service, residential Wi-Fi, enterprise Wi-Fi, Internet Service Providers, and Wi-Fi ecosystem companies). As outlined above, the economic value for each agent will be measured based on three potential economic dimensions: consumer surplus, producer surplus, and GDP growth.

The assessment of economic value will be conducted according to three allocation alternatives described in the introduction:

1. Full allocation of the 1200 MHz of the 6 GHz band for unlicensed use, which allows the aggregation in channels of 160 MHz, leading to doubling the maximum channel bandwidth from its predecessor technology and improving the maximum speed.
2. An estimation of the economic value if the 6 GHz band were to be split between unlicensed spectrum and IMT, allocating the lower 500 MHz for Wi-Fi and the upper 700 MHz band for use by telecommunication service providers. This option would enable an auction of 700 MHz for development of 5G and 6G.
3. A quantification of value of a mi-point option that will allocate 1100 MHz for unlicensed use and 100 MHz to IMT.

Total economic value will result from adding the estimates of the five scenarios. Table 2-1 formalizes each source of value creation by economic agent and Wi-Fi scenarios.

¹⁸ See the prior research in Thanki, R. (2009); Milgrom, et al. (2011); Cooper, M. (2011); Katz, R. (2014a); Katz, R (2014b); and Katz, R. (2018).

Table 2-1. Sources of economic value of Wi-Fi by economic agent

Agents	Sources	GDP contribution	Producer surplus	Consumer surplus
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites			Savings for consumers due to using free Wi-Fi
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population	Increase in GDP due to enhanced broadband adoption		
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E			Consumer surplus from faster data download rate as enabled by faster broadband
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions			Savings for students due to using Wi-Fi in educational institutions
	1.5. Use of Wi-Fi in highly dense heterogeneous environments			Savings for attendees using Wi-Fi in sports stadiums
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port			Consumer surplus from avoiding paying data due to using Wi-Fi
	2.2. Avoidance of inside wiring investment			Savings for consumers due to avoiding investing in internal wiring
	2.3. Consumer benefit derived from faster broadband speed			Consumer surplus from increasing speed
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment			Consumer surplus derived from additional sales of residential Wi-Fi devices and equipment
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas	Improved affordability associated with broadband provision in the WISP sector		
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		Cost reduction of enterprise use of wireless communications	
	3.2. Avoidance of enterprise building inside wiring		Savings for enterprises due to avoiding investing in internal wiring	
	3.3. Benefits derived from an increase in average speed	Increased economic impact due to faster internet speed		
	3.4. Benefits derived from reduced latency	Increased economic impact due to reduced latency		
	3.5. Enhanced IoT deployment	Spillovers of IoT deployment on productivity on key sectors of the Indian economy (e.g., automotive, food processing, logistics, etc.)		
	3.6. Deployment of Augmented Reality/Virtual Reality solutions	Spillovers of AR/VR deployment on the Indian economy		
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		Cost reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers	Revenues of service providers offering paid Wi-Fi due to increase in connected devices		
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers	Revenues of WISP providers due to new subscribers		
5. Wi-Fi ecosystem	5.1. Manufacturing of residential Wi-Fi devices and equipment		Producer surplus derived from additional sales of residential Wi-Fi devices and equipment	
	5.2. Manufacturing of Wi-Fi enterprise equipment		Producer surplus derived from additional sales of enterprise Wi-Fi devices and equipment	
	5.3. Benefits of firms of Internet of Things ecosystem		Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment	

	5.4. Benefits of firms of AR/VR solutions ecosystem		Margins of ecosystem firms involved in AR/VR deployment	
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Source: Telecom Advisory Services

The above table presents an overview of the different sources of Wi-Fi economic value channeled to each economic agent under different Wi-Fi standards operating in different frequency bands.

3. ECONOMIC VALUE OF ALLOCATING THE FULL 6 GHz BAND FOR Wi-Fi

The allocation of the 1200 MHz of the 6 GHz for unlicensed use would yield economic value across five main effects:

- Increase in GDP and consumer surplus resulting from providing free Internet access to consumers that lack residential broadband.
- Faster Internet access in residences as a result of eliminating router bottleneck in high-speed connections.
- Cost reduction for enterprise wireless use.
- Revenues for service providers offering paid Wi-Fi service.
- Development of an ecosystem of Wi-Fi enabled products and services.

Each effect will be assessed in terms of its economic contribution, differentiating between GDP, consumer and producer surplus.

3.1. Free Wi-Fi service

According to Wi-Fi Map (2024)¹⁹, there are 705,514 free Wi-Fi sites in India, which enable individual consumers to access the internet for limited time. This quantity of free Wi-Fi hotspots is much lower than those originally projected by the National Digital Communications Policy of 2018 (which forecasted 10 million public hotspots by 2022), as those provisions have not been met so far.²⁰ Free Wi-Fi hotspots include those deployed in retail outlets (stores, coffee shops, etc.), transportation hubs, and points of delivery of public services (hospitals, doctors offices, public libraries, etc.) among others.

The economic value of free Wi-Fi service originates from five contribution sources:

- Savings incurred by consumers by accessing free Wi-Fi in public sites rather than incurring cellular costs
- Free Wi-Fi service supporting the needs of the broadband unserved population
- Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E
- Benefit to consumers relying on Wi-Fi in educational institutions: avoidance of the purchase of mobile data services in educational institutions
- Use of Wi-Fi in highly dense heterogeneous environments

Each source will be described and assessed in terms of economic value. While data in this chapter is presented in tables between 2024 and 2030, the overall value is assessed for 2024-2034.

3.1.1. Wireless data savings for consumers from accessing free Wi-Fi in public sites

Free Wi-Fi offered in retail shops, coffee shops, city halls, and corporate guest accounts allows consumers to save money that would otherwise be spent purchasing cellular service. In addition, free hotspots provide access to the Internet for consumers that cannot afford to

¹⁹ *Free Wi-Fi in India*. Retrieved in: <https://www.wifimap.io/106-india> in October 2024.

²⁰ The quantity of free Wi-Fi hotspots provided by Wi-Fi Map has been validated through the interviews conducted with local experts.

purchase broadband service. This last effect was particularly important during the coronavirus pandemic, allowing broadband unserved households to access the Internet for telecommuting, telemedicine, and remote education, among other applications.

To estimate the amount consumers can save by use free public Wi-Fi, we start by quantifying the Internet traffic by wireless data-enabled devices (smartphones, tablets, PCs).

The increased adoption of devices combined with an increase in usage has driven overall Internet traffic growth. Forecasts of the installed base of these devices in India shows a steady rise from 2023 to 2030 for smartphones and tablets, and a reduction in the case of laptops. As can be seen in Table 3-1, most Indian residents rely on smartphones to connect to internet, being tablets and laptops used only by a minority.

Table 3-1. India: Device Installed Base and Penetration (2023-2030)

Device	Metrics	2023	2024	2025	2026	2027	2028	2029	2030	CAGR
Smartphones	Units (in million)	927.6	1,012.4	1,083.6	1,142.2	1,189.8	1,227.9	1,258.1	1,282.0	4.73%
	Penetration (%)	64.93%	70.22%	74.49%	77.85%	80.41%	82.32%	83.68%	84.60%	3.85%
Tablets	Units (in million)	57.8	68.8	82.0	97.7	116.4	138.7	165.3	197.0	19.15%
	Penetration (%)	4.04%	4.78%	5.64%	6.66%	7.87%	9.30%	10.99%	13.00%	18.15%
Laptops	Units (in million)	42.4	42.3	42.2	42.1	42.0	41.9	41.8	41.7	-0.23%
	Penetration (%)	2.97%	2.93%	2.90%	2.87%	2.84%	2.81%	2.78%	2.75%	-1.07%
Devices per user		0.719	0.719	0.779	0.830	0.874	0.911	0.944	0.975	1.003

Sources: Cisco Annual Internet Report Highlights Tool 2018-2023; Telecom Advisory Services analysis

Adding to the proliferation of devices, traffic per device is also estimated to increase significantly. The average monthly traffic per device in India is projected to rise considerably from 2023 to 2030 (see Table 3-2).

**Table 3-2. India: Average Traffic Per Device (gigabytes per month)
(2023-2030)**

Device	2023	2024	2025	2026	2027	2028	2029	2030	CAGR
Smartphones	4.9	6.3	8.1	9.5	11	12.8	14.9	17.4	19.85%
Tablets	10.5	12.5	14.8	15.9	17	18.2	19.5	20.9	10.33%
Laptops	39.7	44.8	50.4	51.1	51.8	52.5	53.2	53.9	4.47%

Sources: Cisco Annual Internet Report Highlights Tool 2018-2023; Telecom Advisory Services analysis

The installed base of devices times traffic per device drives overall traffic growth (see Table 3-3).

Table 3-3. India: Internet Traffic (2023-2030)
(exabytes per month)

Device	2023	2024	2025	2026	2027	2028	2029	2030	CAGR
Smartphones	4.193	5.921	8.200	10.065	12.207	14.669	17.502	20.765	25.68%
Tablets	0.159	0.224	0.315	0.399	0.506	0.640	0.810	1.026	30.48%
Laptops	1.366	1.531	1.716	1.731	1.746	1.761	1.776	1.791	3.94%

Sources: Cisco Annual Internet Report Highlights Tool 2018-2023; Telecom Advisory Services analysis

This growth has and will continue to put pressure on the public networks of all wireless service providers to accommodate the traffic without incurring congestion. Based on the premise that cellular off-loading varies by device, we assume the portion of overall mobile traffic by device transmitted through Wi-Fi, which is conservatively set at 30% for the forthcoming years (see Table 3-4).²¹

Table 3-4. India: Wireless Device Off-Loading Factors (2023-2030)

Device	2023	2024	2025	2026	2027	2028	2029	2030
Smartphones ²²	30%	30%	30%	30%	30%	30%	30%	30%
Tablets	30%	30%	30%	30%	30%	30%	30%	30%
Laptops	30%	30%	30%	30%	30%	30%	30%	30%

Sources: Cisco Annual Internet Report Highlights Tool 2018-2023; Jain (2021); interviews conducted; Telecom Advisory Services analysis

By applying these off-loading factors to the total data traffic generated by each type of device, we estimate that total Wi-Fi traffic in India is currently 2.3 Exabytes per month in 2024 and will reach 7.0 by 2030 (see Table 3-5).

Table 3-5. India: Total Wi-Fi Traffic (2023-2030)
(exabytes per month)

Device	2023	2024	2025	2026	2027	2028	2029	2030	CAGR
Smartphones	1.258	1.776	2.460	3.019	3.662	4.401	5.251	6.230	25.68%
Tablets	0.047	0.066	0.093	0.117	0.147	0.185	0.232	0.292	29.63%
Laptops	0.407	0.453	0.505	0.506	0.507	0.508	0.509	0.510	3.26%
Total	1.713	2.296	3.058	3.642	4.316	5.093	5.992	7.031	22.35%

Sources: Cisco Annual Internet Report Highlights Tool 2018-2023; Telecom Advisory Services analysis

The estimation of consumer surplus proceeds, then, by multiplying the total Wi-Fi traffic from Table 3-5 by 4.32%, our estimate of the amount of traffic using free Wi-Fi access points²³ (Table 3-6).

²¹ This figure for Wi-Fi offloading was used in previous studies for India (Jain, 2021) and has been validated through the interviews conducted with local experts. While it is expected to increase, we purposely decided to leave it unchanged in our estimations in order to provide a conservative scenario.

²² In 2023, the smartphone offloading factor grew to an average of 50%, which would imply an increase in economic value. We prefer to continue estimating 48% for conservative purposes, because we lack data as to whether that increase will be permanent.

²³ We assume a constant number for 4.32% of total Wi-Fi going through public sites. Considering that 52% of this amount in 2024 goes through free hot spots, at 2.25% remains a conservative assumption. This has been used as a constant number for past reports although recent qualitative data indicates that this percent has been growing.

Table 3-6. India: Total Public Wi-Fi Traffic (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Wi-Fi traffic (exabytes per month)	2.296	3.058	3.642	4.316	5.093	5.992	7.031
Total Public Wi-Fi traffic (exabytes per month)	0.099	0.132	0.157	0.187	0.220	0.259	0.304
Total Public Wi-Fi traffic (exabytes per year)	1.191	1.586	1.889	2.239	2.642	3.108	3.647
Total Public Wi-Fi traffic (million GB per year)	1,278.977	1,703.062	2,028.558	2,403.883	2,836.903	3,337.217	3,916.357

Sources: Cisco; Telecom Advisory Services analysis

The consumer surplus generated by free Wi-Fi sites is composed of two sources: the benefit originated by unlicensed spectrum operating in the 2.4 GHz and 5 GHz bands and that derived from allocating the entire 6 GHz band for Wi-Fi use. To isolate the effect from the increased capacity derived from the 6 GHz allocation, we calculate the portion of free Wi-Fi traffic attributed to current spectrum bands. For this, we relied on the assumption that current traffic levels are already producing congestion in most free Wi-Fi hotspots at times of peak demand. Thus, we assume that traffic per hotspot beyond 2021 has remained at the average 2020 levels (974 GB per year, per hotspot) (See Table 3-7).

Table 3-7. India: Total free Wi-Fi Traffic projection (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Public Wi-Fi traffic (million GB per year)	1,278.977	1,703.062	2,028.558	2,403.883	2,836.903	3,337.217	3,916.357
Free Wi-Fi hotspots (million)	0.71	0.82	0.94	1.09	1.26	1.46	1.69
Annual traffic per hotspot - considering current trends (GB)	1,813	2,086	2,147	2,199	2,243	2,280	2,312
Annual traffic per hotspot - capped due to congestion (GB)	974	974	974	974	974	974	974
Total traffic (not attributed to 6 GHz allocation) (million GB)	687	795	920	1,065	1,232	1,426	1,650

Sources: Cisco; Wi-Fi Map; Telecom Advisory Services analysis

We calculate consumer benefit by multiplying the total free traffic (not attributed to 6 GHz) by the difference between what the consumer would have to pay if she/he were to rely on a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we need an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic “US dollar per GB” plan of Indian wireless carriers (US\$ 0.10).²⁴ Starting from this previous estimate of a price per GB in 2024 of \$ 0.10, we expect the average price per GB will reach an estimated US\$ 0.06 in 2030.

As to the cost of offering the free Wi-Fi service, the counterfactual option, this would include an additional router and bandwidth for the provider of free service.²⁵ We assume those costs represent the same share of the GB price as in the United States (assuming this to be costs passed through to the customer). By relying on the total free Wi-Fi traffic not attributed to 6 GHz allocation shown in Table 3-7 and the average price per cellular gigabyte minus the cost of provisioning Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic relying on the 2.4 GHz and 5 GHz bands (see Table 3-8).

²⁴ The US dollar per GB is calculated by prorating by market share the least expensive plans for Jio, Airtel and Vi. This calculation yields 8.56 rupees, which is converted to US\$ 0.10.

²⁵ The cost of provisioning fixed broadband is not accounted since those are already part of the existing infrastructure of the location where the user of free service is.

Table 3-8. India: Consumer surplus of free Wi-Fi traffic in the 2.4 and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Free Traffic (not attributed to 6 GHz) (million GB)	687	795	920	1,065	1,232	1,426	1,650
Price per cellular gigabyte (US\$)	0.10	0.09	0.09	0.08	0.07	0.07	0.06
Cost per Wi-Fi provisioning (US\$)	0.07	0.06	0.06	0.05	0.05	0.04	0.04
Consumer benefit per gigabyte (US\$)	0.04	0.03	0.03	0.03	0.03	0.02	0.02
Total Consumer surplus (US\$ million)	\$ 25.53	\$ 27.08	\$ 28.72	\$ 30.45	\$ 32.29	\$ 34.25	\$ 36.32

Sources: Websites of cellular operators; Telecom Advisory Services analysis

As indicated in Table 3-8, consumer surplus of free Wi-Fi traffic in the 2.4 GHz and 5 GHz bands 2024 was an estimated US\$ 25.5 million, increasing to US\$ 36.6 million to 2030.

The allocation of the 6 GHz spectrum band for unlicensed use and the technological advancements provided by the Wi-Fi 6E standard would alleviate some of the previously mentioned bottlenecks causing congestion. Consequently, the traffic per hotspot will continue to grow at its natural rate, as determined by the extrapolation of recent trends. Based on these projections, the total traffic attributable to use of the 6 GHz band will grow from 299 million GB in 2024, to 1,345 million GB in 2030 (See Table 3-9).

Table 3-9. India: Free Wi-Fi Traffic generated due to allocation of the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Traffic per hotspot (capped due to congestion Wi-Fi 6E) (GB)	1,813	1,813	1,813	1,813	1,813	1,813	1,813
Free Wi-Fi hotspots (million)	0.71	0.82	0.94	1.09	1.26	1.46	1.69
Total traffic (million GB)	1,279	1,480	1,713	1,982	2,293	2,654	3,071
Additional traffic through the 6 GHz band (million GB)	592	685	792	917	1,061	1,227	1,420
Traffic through the 6 GHz band (%)	51%	66%	77%	84%	89%	92%	95%
Total Free traffic (attributable to the 6 GHz band) (million GB)	299	451	606	768	942	1,133	1,345

Sources: Cisco; Wi-Fi Map; Telecom Advisory Services analysis

Once we compute the additional traffic due to the 6 GHz band, we follow a similar approach to calculate the consumer surplus, by multiplying it by the difference between what the consumer would have to pay if he were to utilize a wireless carrier and the cost of offering free Wi-Fi (Table 3-10). As a result, we project an additional consumer benefit of \$ 29.59 million from free Wi-Fi traffic attributed to the 6 GHz in 2030.

Table 3-10. India: consumer benefit of free Wi-Fi traffic due to allocation of the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Free traffic (attributable to the 6 GHz band) (million GB)	299	451	606	768	942	1,133	1,345
Price per cellular gigabyte (US\$)	0.10	0.09	0.09	0.08	0.07	0.07	0.06
Cost per Wi-Fi provisioning (US\$)	0.07	0.06	0.06	0.05	0.05	0.04	0.04
Consumer benefit per gigabyte (US\$)	0.04	0.03	0.03	0.03	0.03	0.02	0.02
Total Consumer benefit (US\$ Million)	\$ 11.12	\$ 15.36	\$ 18.91	\$ 21.96	\$ 24.69	\$ 27.20	\$ 29.59

Sources: Websites of cellular operators; Telecom Advisory Services analysis

In sum, the consumer surplus for accessing internet access in free Wi-Fi sites amounts to US\$ 37 million in 2024, reaching US\$ 85 million in 2034 (see table 3-11).

Table 3-11. India: Consumer surplus of free Wi-Fi access (million US\$) (2024-2034)

Variable	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
2.4 GHz and 5 GHz bands	\$ 25.53	\$ 27.08	\$ 28.72	\$ 30.45	\$ 32.29	\$ 34.25	\$ 36.32	\$ 38.51	\$ 40.84	\$ 43.31	\$ 45.93
6 GHz band	\$ 11.12	\$ 15.36	\$ 18.91	\$ 21.96	\$ 24.69	\$ 27.20	\$ 29.59	\$ 31.93	\$ 34.26	\$ 36.62	\$ 39.05
Total	\$ 36.65	\$ 42.44	\$ 47.62	\$ 52.41	\$ 56.98	\$ 61.45	\$ 65.91	\$ 70.44	\$ 75.10	\$ 79.94	\$ 84.98

Sources: Websites of cellular operators; Telecom Advisory Services analysis

3.1.2. Free Wi-Fi service supporting the needs of the broadband unserved population

Deployment of free Wi-Fi provides Internet access to the unserved population. Consumers that do not have broadband at home because they lack the economic means to acquire services can rely on free Wi-Fi to gain Internet access. As a result, more people can be connected, which in turn enhances the economic contribution of broadband.

The calculation of this economic impact starts by calculating which portion of Indian households that lack broadband service are already accessing the Internet through free hotspots. Statista reported that by the end of 2023 there were 141,678,635 households with internet access in India (fixed or mobile). The estimation of non-connected households is based on the number of households (294,292,700), which results in a total non-connected as of 2023 of 153 million. We follow a conservative approach and assume that only 5% of unconnected households rely on free hotspots for accessing the Internet.²⁶ After calculating the increase in broadband penetration due to households relying on free Wi-Fi, we rely on the broadband impact coefficient from Katz and Callorda (2024), that estimates for the Asia Pacific region a 1.62% increase in GDP for every 10% increase in penetration. As a result, the GDP contribution of this effect is expected to amount to US\$ 29 billion in 2024, evolving to \$10 billion in 2030 (see table 3-12).

²⁶ This figure was validated in the interviews conducted

Table 3-12. India: GDP contribution due to households relying on free Wi-Fi in the 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Households without Internet	141,798,884	129,324,744	115,000,150	98,612,256	79,924,499	58,673,970	49,318,028
Households that don't buy because access the Internet via free hotspots (%)	5%	5%	5%	5%	5%	5%	5%
Households served by free Wi-Fi hot spots	7,089,944	6,466,237	5,750,007	4,930,613	3,996,225	2,933,699	2,465,901
Households with Broadband	157,380,000	174,821,450	194,195,827	215,717,346	239,623,962	266,180,000	280,929,539
Increase in national broadband penetration	4.50%	3.70%	2.96%	2.29%	1.67%	1.10%	0.88%
Impact of broadband adoption in GDP	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%
Increase in the GDP due to the new broadband adoption (% GDP)	0.73%	0.60%	0.48%	0.37%	0.27%	0.18%	0.14%
GDP (US\$ billion)	\$ 3,937	\$ 4,340	\$ 4,790	\$ 5,287	\$ 5,833	\$ 6,437	\$ 7,102
Total impact in GDP (US\$ million)	\$ 28,733	\$ 26,004	\$ 22,975	\$ 19,577	\$ 15,760	\$ 11,493	\$ 10,099

Sources: TRAI; STATISTA; IMF; Katz and Callorda (2024); Telecom Advisory Services analysis

Moving on to the use of the 6 GHz band, Wi-Fi 6E technology supports a high number of devices on a single access point. Accordingly, the improved throughput of free Wi-Fi hotspots under the 6 GHz allocation will allow for the possibility of serving additional unconnected households. We follow again a conservative approach and assume that a further 5% of unconnected households are served through free hotspots with the technological advantages of Wi-Fi 6E. We have also considered that the expansion of traffic through the new band, with Wi-Fi 6E will take place gradually, reaching 65.93% in 2025. All in all, we estimate that additional 4 million households will be served in 2025 due to free hotspots operating under 6 GHz spectrum, yielding an additional GDP contribution of approximately US\$ 14 billion in 2024, reaching US\$ 9.0 in 2030 (Table 3-13).

Table 3-13. India: GDP contribution due to households relying on Free Wi-Fi in the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Households without Internet (not served by free Wi-Fi and not new adopters of WISP)	134,593,831	122,698,346	109,049,230	93,446,679	75,663,892	55,447,114	46,532,268
Potential households that could be served through free Wi-Fi hotspots under increased capacity (% of those not connected)	5%	5%	5%	5%	5%	5%	5%
Traffic through Wi-Fi 6E (%)	51%	66%	77%	84%	89%	92%	95%
Additional households served by free Wi-Fi hotspots with Wi-Fi 6E	3,405,015	4,044,900	4,171,545	3,915,416	3,360,564	2,558,787	2,203,019
Increase in national broadband penetration	2.16%	2.31%	2.15%	1.82%	1.40%	0.96%	0.78%
Increase in the GDP due to the new broadband adoption (% GDP)	0.35%	0.37%	0.35%	0.29%	0.23%	0.16%	0.13%
Total impact in GDP (US\$ million)	\$ 13,799	\$ 16,267	\$ 16,668	\$ 15,546	\$ 13,253	\$ 10,024	\$ 9,023

Sources: TRAI; STATISTA; IMF; Katz and Callorda (2024); Telecom Advisory Services analysis

In sum, the GDP contribution for providing internet access in free Wi-Fi sites to consumers lacking residential service amounts to US\$ 42.5 billion in 2024, reaching US\$ 31.7 billion in 2034 (see table 3-14).

Table 3-14. India: GDP contribution of free Wi-Fi access (billion US\$) (2024-2034)

Variable	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
2.4 GHz and 5 GHz bands	\$ 28.7	\$ 26.0	\$ 23.0	\$ 19.6	\$ 15.8	\$ 11.5	\$ 10.1	\$ 10.3	\$ 11.6	\$ 13.7	\$ 16.4
6 GHz band	\$ 13.8	\$ 16.3	\$ 16.7	\$ 15.5	\$ 13.3	\$ 10.0	\$ 9.0	\$ 9.4	\$ 10.7	\$ 12.7	\$ 15.3
Total	\$ 42.5	\$ 42.3	\$ 39.6	\$ 35.1	\$ 29.0	\$ 21.5	\$ 19.1	\$ 19.7	\$ 22.3	\$ 26.4	\$ 31.7

Sources: Websites of cellular operators; Telecom Advisory Services analysis

3.1.3. Benefit to consumers enjoying higher speed from free Wi-Fi operating in the 6 GHz band

In addition to providing increased access to consumers lacking residential broadband, when the 6 GHz band is adopted by free Wi-Fi access points, it delivers service at faster broadband speeds. We estimate that public Wi-Fi hotspots in 2024 averaged 15.62 Mbps of download speed²⁷. Thus, the expanded capabilities due to the allocation of 6 GHz spectrum band will enhance free Wi-Fi speed using Wi-Fi 6E, and as a result, will increase consumer benefit. We assume that relying on the 6 GHz allocation, speed from free hotspots will be similar as one third of the average download speed in households (assuming that the number of devices connected to a mobile hotspot at the same time is on average three times less than the devices

²⁷ Taking as a reference speeds reported by Ookla for the Mumbai Airport. In the interviews conducted, this speed level was considered reasonable to be used as a free Wi-Fi average.

connected at home²⁸). After calculating the average speed by considering the expected share of traffic through Wi-Fi 6E, we follow Nevo et al. (2016) and calculate the additional consumer benefit per household relying on free Wi-Fi. We expect the benefit resulting from faster speed in free Wi-Fi sites to reach US\$ 191 million in 2030 due to Wi-Fi 6E in the 6 GHz band (see table 3-15).

Table 3-15. India: consumer benefit for enjoying higher speed from free Wi-Fi with Wi-Fi 6E (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Free Wi-Fi mean speed with no Wi-Fi 6E (Mbps)	15.62	16.56	17.56	18.62	19.75	20.94	22.21
Free Wi-Fi mean speed with Wi-Fi 6E (Mbps)	27.73	29.22	30.79	32.44	34.18	36.01	37.95
Traffic through Wi-Fi 6E (%)	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Average Free Wi-Fi mean speed with Wi-Fi 6E (Mbps)	21.75	24.91	27.68	30.20	32.57	34.85	37.11
Demand for average download speed	24.57	24.96	25.35	25.74	26.13	26.52	26.91
New Demand for average download speed	26.77	27.67	28.37	28.95	29.45	29.90	30.32
Additional Monthly Consumer Benefit	2.20	2.71	3.02	3.21	3.32	3.38	3.41
Additional Yearly Consumer Benefit	26.38	32.52	36.26	38.54	39.88	40.61	40.94
Households that rely on Free Wi-Fi	10,494,959	10,511,137	9,921,553	8,846,029	7,356,789	5,492,485	4,668,920
Impact (US\$ million)	\$276.89	\$341.86	\$359.80	\$340.91	\$293.37	\$223.05	\$191.14

Sources: Nevo et al. (2016); Telecom Advisory Services analysis

3.1.4. Benefit to consumers relying on Wi-Fi in educational institutions

This analysis is based on a detailed financial analysis of the cost of Wi-Fi in educational institutions, focusing on capital expenditures (CAPEX) and operational expenditures (OPEX) for 19,000 students, as a case study constructed for a particular US school.²⁹ The CAPEX, which is a one-time investment, is amortized at US\$128,571 per year from 2023 to 2027, reaching a total investment of US\$900,000 over seven years. The OPEX, representing the annual operational costs, remains steady at \$742,000 per year. Consequently, the yearly cost per student is calculated at \$45.62, derived by dividing the sum of CAPEX and OPEX by the total number of students, which is 19,000. This number is adjusted to the case of India as \$ 11.19, by considering the PPP converting factor.

Enrollment data from the Indian Ministry of Education and the World Bank is used to determine the total number of students at various educational levels: higher education, secondary school, and elementary school, resulting in a consistent total population of 355.5

²⁸ Our starting point is the speed that we get from a single device when connected through Wi-Fi at home, which is reported by Ookla (289 Mbps) in 2023. Now, since we do not have the speed data in free Wi-Fi connections, we thought that this being a shared connection, the speed should be lower. Our assumption of a third of speed is qualitatively confirmed by interviews that the upgrade of free sites to higher standards is proceeding very slowly.

²⁹ The original estimate was developed in Katz, R. (2022). *The “to and through” opportunity: An economic analysis of options to extend affordable broadband to students and households via anchor institutions: Economic analysis, Cost Calculation Toolkit and Public Policy Implications*. New York: Telecom Advisory Services and is based on the case study of a US High School District.

million students in 2021. The analysis assumes no increase in enrollment numbers for conservative purposes. Additionally, the share of time spent on homework is estimated for different education levels: 25% for higher education, 20% for secondary school, and 15% for elementary school. The weighted average share of time spent on homework, across all levels, is 18.63% in 2024, increasing to 27.85% in 2034.

The analysis also examines the counterfactual expenses associated with using Mobile Broadband (MBB) for educational purposes, considering it as an alternative to Wi-Fi. The total cost of using MBB is projected to decrease annually from US\$ 445 in 2024 to US\$ 264 in 2030.³⁰ This reduction is calculated using the same rate applied to the price of one gigabyte of mobile broadband. Additionally, it is important to note that only a share of this cost is relevant, as it represents the proportion of time spent using data for homework. Consequently, the adjusted cost ranges from US\$ 83 in 2024 to US\$ 63 in 2030.

The yearly benefit per student, calculated as the difference between the adjusted cost using MBB and the yearly cost per student to have Wi-Fi in schools, decreases from \$71.80 in 2024 to \$51.38 in 2027 (reflecting the declining cost of mobile broadband). Finally, the total consumer benefit, determined by multiplying the yearly benefit per student by the number of students, declines from \$25,528 million in 2024 to \$18,268 million in 2030 (see Table 3-16).

Table 3-16. India: Benefit to consumers relying on Wi-Fi in educational institutions (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Yearly cost per student (US\$)	\$ 11.19	\$ 11.19	\$ 11.19	\$ 11.19	\$ 11.19	\$ 11.19	\$ 11.19
Total enrollment	355,537,347	355,537,347	355,537,347	355,537,347	355,537,347	355,537,347	355,537,347
Share of time in education	18.63%	19.40%	20.19%	21.02%	21.88%	22.78%	23.71%
Total Cost using MBB (US\$)	\$ 445.39	\$ 408.18	\$ 374.07	\$ 342.82	\$ 314.17	\$ 287.92	\$ 263.87
Real Cost using MBB (US\$)	\$ 82.99	\$ 79.17	\$ 75.53	\$ 72.06	\$ 68.75	\$ 65.59	\$ 62.57
Yearly benefit by student (US\$)	\$ 71.80	\$ 67.98	\$ 64.34	\$ 60.87	\$ 57.56	\$ 54.40	\$ 51.38
Consumer surplus	\$ 25,528	\$ 24,171	\$ 22,877	\$ 21,642	\$ 20,464	\$ 19,340	\$ 18,268

Sources: Verizon website; US Census; World Bank; Telecom Advisory Services analysis

Despite the decline in mobile broadband costs, the benefit of Wi-Fi in supporting educational needs is clear.

3.1.5. Use of Wi-Fi in highly dense heterogeneous environments

By leveraging the 6 GHz band, Wi-Fi 6E can offer faster speeds and greater capacity, ensuring that attendees in highly dense environments such as at professional sporting events can enjoy seamless connectivity for activities such as streaming video, accessing social media, and utilizing various data-intensive applications. Sports venues across the world have already started deploying these facilities.³¹

Attendance at these events is expected to grow steadily with mobile data usage per user increasing significantly each year³². The adoption rate of Wi-Fi 6E is estimated at 50.60% in 2024 and reaches 94.69% in 2030. Yearly traffic handled by Wi-Fi 6E is projected to reach 85 million GB in 2030.

³⁰ Average based on the assessment reported above.

³¹ See for example: <https://www.sportsvideo.org/2024/04/24/san-francisco-giants-oracle-park-byus-lavell-edwards-stadium-tap-6-ghz-wi-fi-connectivity/>

³² Based on average data use per match in Qatar Soccer World Cup

In the calculation, we also consider the capital expenditure for Wi-Fi 6E infrastructure, that remains constant at US\$ 0.31 million per year. Finally, the consumer benefit is calculated by comparing the savings from using Wi-Fi 6E to the costs of mobile data. The consumer surplus is projected to gradually increase reflecting slow adoption in sport venues (see Table 3-17).

Table 3-17. India: Use of Wi-Fi in highly dense heterogeneous environments using the 6 GHz band (2023-2030)

Variable	2023	2024	2025	2026	2027	2028	2029	2030
Attendance to professional sporting events (yearly)	41,100,000	41,500,000	41,800,000	42,000,000	42,100,000	42,200,000	42,911,814	43,635,635
Mobile data usage per user, per match (GB)	0.47	0.59	0.72	0.89	1.10	1.36	1.67	2.06
Traffic through Wi-Fi 6E (%)	28.36%	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Yearly traffic using Wi-Fi 6E (GB)	5,535,071	12,299,565	19,911,600	28,635,017	38,777,777	50,820,130	66,228,487	85,217,942
Cost of the traffic using mobile network	\$ 0.11	\$ 0.10	\$ 0.09	\$ 0.09	\$ 0.08	\$ 0.07	\$ 0.07	\$ 0.06
CAPEX (in price of sporting event)	\$ 0.31	\$ 0.31	\$ 0.31	\$ 0.31	\$ 0.31	\$ 0.31	\$ 0.31	\$ 0.31
Consumer surplus (US\$ million)	\$ 0.31	\$ 0.95	\$ 1.56	\$ 2.16	\$ 2.75	\$ 3.37	\$ 4.08	\$ 4.87

Sources: Telecom Advisory Services analysis

As stated above, this estimate should be conservative considered additional boost in 6 GHz use derived from the launch of Wi-Fi 7.

* * * * *

In sum, the use of Wi-Fi technology in sites accessed for free represents an important source of economic value:

- Free Wi-Fi offered in retail shops, coffee shops, city halls, and corporate guest accounts allows consumers to save money that would otherwise be spent purchasing cellular service: this amounts to US\$ 37 million in 2024, reaching US\$ 85 million in 2034.
- Free Wi-Fi service supporting the needs of the broadband unserved population: assuming conservatively that only 5% of 141.8 million unconnected households rely on free Wi-Fi sites to support their connectivity needs and considering the contribution of broadband lines to the GDP, Wi-Fi will increase GDP by US\$ 41.7 billion in 2024 and US\$ 30.8 billion in 2034.
- Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E operating in the 6GHz band which amounts to US\$ 260 million in 2024 and US\$ 209 million in 2034.
- Benefit to consumers relying on Wi-Fi rather than purchasing mobile data services in educational institutions, which ranges between US\$ 25.5 billion in 2024 and US\$ 14.5 billion in 2034.

- Use of Wi-Fi in highly dense heterogeneous environments: consumer benefit in settings, such as stadiums where large numbers of users are accessing the network simultaneously, reaching US\$ 9.13 million in 2034.

3.2. Residential use

Wi-Fi is a critical component of a home's infrastructure. It is an enabler of wireless communication between the point of access of fixed broadband and among multiple devices, such as data processing equipment, sound systems, home security, appliances, and the like. As a consequence, WI-FI is becoming not only a support fixed broadband wireless interface, but also a critical inter-device connectivity device, which is the reason why Wi-Fi routers are becoming pervasive: as of 2024, 60% of Indian households that subscribe to fixed broadband are assumed to be equipped with Wi-Fi networks.

This level of adoption drives economic contribution at multiple levels:

- Due to the technology features, Wi-Fi, especially Wi-Fi 6E operating in the 6 GHz band is faster than mobile broadband.
- Wi-Fi represents an infrastructure that supports in-home device connectivity avoiding the need to deploy Ethernet cable in each room, an expensive proposition.
- In the absence of Wi-Fi, the traffic of devices lacking an Ethernet port, such as smartphones and tablets, would have to depend on the cellular networks to gain Internet access (although we acknowledge that adaptors exist that allow hooking up these devices to the wired Ethernet).
- WI-FI enables the adoption of a multiplicity of devices that propel consumer benefit (such as alarm systems).
- Wi-Fi is an integral component of wireless ISPs (called WISPs) that provide broadband connectivity for unserved communities. The contribution to GDP of wireless broadband access materializes through multiple effects: creation of new businesses, increasing productivity of existing enterprises, and growth of average income per household
- The growing integration of digital technologies in the automotive industry is driving increased adoption of Wi-Fi in new use cases yielding consumer benefit.

3.2.1. Consumer surplus derived from faster broadband speed

Consumer benefit increases if users enjoy faster Internet speeds, which is why they expect to pay more for faster broadband. Therefore, residential Wi-Fi customers are expected to benefit from faster services than those provided by cellular networks, as a counterfactual alternative (see appendix A). It is important to note that this consumer surplus only benefits households with Wi-Fi 6E and those with Internet and Wi-Fi. For example, in 2024, 50.6% of traffic is assumed through Wi-Fi 6E, and there were 25 million households with Internet and Wi-Fi. The impact is calculated by multiplying the additional consumer benefit, the percentage of traffic through Wi-Fi 6E, and the number of households. This results in an impact of \$57 million in 2024, increasing to \$4,126 million in 2034 (see Table 3-18).

Table 3-18. India: Consumer benefit from faster speed in households with 6 GHz (2024-2027)

Variable	2024	2025	2026	2027	2028	2029	2030
Households that have connections over 150 Mbps (%)	3.46%	5.44%	7.62%	10.23%	13.36%	17.09%	21.52%
Percentage of household traffic that goes through Wi-Fi	73.25%	76.21%	78.94%	81.44%	83.70%	85.73%	87.54%
Share of traffic affected	2.54%	4.15%	6.01%	8.33%	11.18%	14.65%	18.84%
Avg Fixed broadband Speed (Mbps) - connections >150 Mbps	300	350	425	500	575	650	750
Max Download speed using Wi-Fi 6E	1,186	1,186	1,186	1,186	1,186	1,186	1,186
CAP Avg Fixed broadband Speed (Mbps) - connections >150 Mbps	300	350	425	500	575	650	750
Mean speed with no Wi-Fi 6E (Mbps)	91	103	116	130	143	156	167
Mean speed with Wi-Fi 6E (Mbps)	96	113	134	161	191	228	277
Demand for average download speed (Nevo Curve) (US\$)	36.25	37.10	37.88	38.63	39.28	39.84	40.31
New Demand for average download speed (Nevo Curve) (\$)	36.63	37.73	38.87	40.05	41.22	42.38	43.67
Additional Consumer Benefit with Wi-Fi 6E Yearly (\$)	4.54	7.57	11.86	17.01	23.20	30.48	40.33
Traffic through Wi-Fi 6E (%)	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Households with internet and Wi-Fi	24,972,510	28,669,374	32,878,928	37,669,405	43,117,864	49,311,308	53,537,105
Impact (US\$ million)	\$57	\$143	\$298	\$537	\$888	\$1,387	\$2,044

Sources: Cisco; Ookla; interviews conducted; Nevo et al. (2016); Telecom Advisory Services analysis

3.2.2. Home Internet access for devices that lack an Ethernet port

The underlying premise of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to gain Internet access. For this reason, estimating value would first measure the traffic generated by these devices at home, and then multiply it by the average price charged by cellular carriers. In calculating this benefit, it is important to consider that it is feasible to connect phones and tablets to the Ethernet through adapters. However, three limits should be considered in assessing the remaining number of devices that cannot be hooked up to the Ethernet:

- Most Android devices and newer iPad models will need a USB-C-to-Ethernet adapter, while older Android phones and tablets should require a micro USB-to-Ethernet adapter. In fact, micro USB to Ethernet cannot deliver speeds as fast as USB-C to Ethernet.
- Furthermore, since USB-C adapters are relatively new to be introduced, one has to reduce a portion of the likely universe out of the potential connectivity universe of users.
- Operationally, the user needs to purchase an Ethernet cable, turnoff the Wi-Fi, refresh the Internet page and then access the Internet.

To estimate the traffic of smartphones and tablets, we relied on Cisco and GSMA estimates and extrapolated those growth rates to 2027 considering both the increase in units and the increase in traffic. According to Cisco IBSG (2012), 43.12% of use time of devices that lack an Ethernet port occurs at home.³³ After that, we estimate that 75% of the traffic generated from smartphones and tablets is relying on Wi-Fi connectivity. Accordingly, the portion of Wi-Fi traffic generated at home will reach 58.6 billion gigabytes in 2027 (see Table 3-19).

³³ While this study is not up to date, our reliance for the analysis indicates a conservative assumption. If one were to adjust this value for the tendency to hybrid work patterns, the share of Wi-Fi traffic at home could be significantly higher. Furthermore, even if the time at home has not changed, the use cases from home have become heavier (e.g., streaming, etc.). Under Wi-Fi, one would assume that the percent of traffic being originated at home has increased.

Table 3-19. India: Total Wi-Fi Traffic at home from mobile devices (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Annual traffic – Smartphones (billion GB)	76.297	105.656	129.684	157.290	189.013	225.509	267.559
Total Annual traffic – Tablets (billion GB)	10.305	14.611	18.646	23.794	30.365	38.749	49.449
Share of traffic at Home (%)	43.12%	43.12%	43.12%	43.12%	43.12%	43.12%	43.12%
Share of traffic at Home using Wi-Fi (%)	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%	75.00%
Total Traffic at Home – Smartphones (billion GB)	24.673	34.167	41.938	50.865	61.124	72.926	86.524
Total Traffic at Home – Tablets (billion GB)	3.332	4.725	6.030	7.695	9.819	12.531	15.991
Total Traffic at Home (billion GB)	28.006	38.892	47.967	58.560	70.943	85.457	102.515
Average Price per Gb (US\$)	\$0.10	\$0.09	\$0.09	\$0.08	\$0.07	\$0.07	\$0.06
Price per home traffic (US\$ million)	\$ 2,876	\$ 3,660	\$ 4,137	\$ 4,628	\$ 5,139	\$ 5,673	\$ 6,236

Sources: Cisco; Websites of cellular operators; Telecom Advisory Services analysis

If this traffic had to be transported by cellular networks, at the average price per GB estimated previously, it would result in costs of US\$ 2.9 billion in 2024, reaching US\$ 6.2 billion in 2030. That is computed as a benefit to consumers.

3.2.3. Avoidance of inside wiring investment

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in a U.S. residence is approximately US\$684 per household, which is equivalent to US\$161 in India after adjusting for PPP.³⁴ Considering that we estimate 60% of Indian households connected with fixed broadband have Wi-Fi in 2024, the avoidance costs of inside wiring for 25 million households yields a total savings of US\$ 4 billion in 2024. To estimate the forward-looking benefit, we only consider the additional value for each year of incremental households that avoid deploying Ethernet wiring. The net result is a saving of US\$ 681 millions in 2030 (See Table 3-20).

Table 3-20. India: Consumer surplus from avoidance of investment in in-house wiring (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Wiring Cost	\$161.17	\$161.17	\$161.17	\$161.17	\$161.17	\$161.17	\$161.17
Households with internet (million)	41.830	46.466	51.615	57.335	63.690	70.748	74.668
Households with internet and Wi-Fi (%)	60%	62%	64%	66%	68%	70%	72%
Households with internet and Wi-Fi (million)	24.973	28.669	32.879	37.669	43.118	49.311	53.537
Inside Wiring Costs (\$ million) yearly	\$4,025	\$4,621	\$5,299	\$6,071	\$6,949	\$7,947	\$8,628
Inside Wiring Costs (\$ million)	\$760.68	\$595.81	\$678.44	\$772.07	\$878.11	\$998.18	\$681.06

Sources: Telecom Advisory Services analysis

3.2.4. Consumer surplus generated by use of residential Wi-Fi devices and equipment

Consumers receive an economic surplus from acquiring Wi-Fi devices at a lower price than their willingness-to-pay for them. The absence of willingness-to-pay data for each piece of equipment makes it very difficult to reliably estimate consumer benefit. To overcome that limitation, a possible approximation is to assume that consumer benefit would equal the producer surplus (see Milgrom et al., 2011). Therefore, we calculate the producer's margin, and attribute that value to the consumer benefit.

³⁴ National average for wiring a 2-room residence with CAT 6. Prices for the US adjusted for the PPP.

The consumer surplus derived from the adoption of residential Wi-Fi devices and equipment focuses on seven consumers products which are intrinsically linked to Wi-Fi: smart home devices and systems such as Wi-Fi speakers and home security systems, home networking systems, Wi-Fi tablets, access points, external adapters, routers, and gateways. Assuming that consumer surplus is roughly equal to producer surplus in four products, we collected data on local sales in the four product categories in India³⁵. After computing the sales in India, we applied the prorated margin estimated by CSI markets (44.59%) which yields an estimated producer surplus for these products of US\$ 525 million in 2024, of which US\$ 117 million are linked to the 6 GHz band (802.11ax standard). As anticipated, we assume these to be of the same magnitude as consumer surplus (see Table 3-21).

Table 3-21. India: Economic Value of Wi-Fi enabled consumer products (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total sales (US\$ million)	1,176	1,327	1,500	1,700	1,931	2,198	2,508
Gross margin	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%
Producer surplus (US\$ million)	\$ 524.57	\$ 591.78	\$ 669.04	\$ 758.08	\$ 860.96	\$ 980.13	\$ 1,118.52
Total Consumer Benefit (US\$ million)	\$ 524.57	\$ 591.78	\$ 669.04	\$ 758.08	\$ 860.96	\$ 980.13	\$ 1,118.52

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; Telecom Advisory Services analysis

Finally, we must consider that part of those sales corresponds to devices in the 2.4 GHz and 5 GHz bands and the share of equipment in the 6 GHz band. According to IDC, global shipments of consumer devices linked to 6 GHz (802.11ax standard) will represent 39.59% of the shipments from previous generations in 2027. Therefore, the consumer benefit generated by products operating in 2.4 GHz and 5 GHz bands is US\$ 407 million in 2024 and US\$ 458 million in 2027 (see table 3-22).

Table 3-22. India: Economic Value of Wi-Fi enabled consumer products operating in 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Global - Total Wi-Fi 6E or more shipments	22.39%	28.72%	34.42%	39.59%	45.52%	52.35%	60.20%
Total Consumer Benefit (US\$ million)	\$ 524.57	\$ 591.78	\$ 669.04	\$ 758.08	\$ 860.96	\$ 980.13	\$ 1,118.52
Total Consumer Benefit (US\$ million) 2.4 GHz and 5 GHz	\$ 407.09	\$ 421.81	\$ 438.74	\$ 457.99	\$ 469.04	\$ 467.04	\$ 445.17
Total Consumer Benefit (US\$ million) 6 GHz	\$ 117.47	\$ 169.97	\$ 230.30	\$ 300.09	\$ 391.93	\$ 513.09	\$ 673.35

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; IDC; Telecom Advisory Services analysis

Conversely, the consumer surplus associated to the 6 GHz band increases from US\$ 117 million in 2024 and reaches US\$ 673 in 2030. This estimate is conservative since it does not include the adoption of Wi-Fi 7 devices relying on the 6 GHz band, expected to start launch in 2025.

3.2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas

³⁵ These categories are WiFi Front-end Modules Market (Power Amplifier (PA), Low Noise Amplifiers (LNA), Switches), routers, access points, and wireless speakers.

Wi-Fi is an appropriate technology to offer Internet access in rural and isolated areas. The increase in WISP connections is directly related to the growth of connections according to the scenarios differentiating the use of 2.4 and 5 GHz bands versus the 6 GHz band. In this regard, in order to analyze the impact of the standard upgrade on the increase of connections in homes in rural and isolated areas, two main aspects must be established: (i) the number of maximum outdoor channels driving the amount of connections that could be deployed (160MHz for Wi-Fi 6E); and, (ii) the number of connections for the allocation of resource units with which similar speeds can be achieved in both standards (8 connections with 242 RU for Wi-Fi 6E to reach 1,186.27 Mbps).

The calculation of the contribution of unlicensed spectrum to the reduction of the digital divide must subtract the direct impact of WISPs detailed below to avoid double counting. On the other hand, we assume that half of WISP potential connections may be theoretically served by other technologies (i.e. satellite) covering the same isolated footprint. Thus, we can conservatively expect 50% of broadband subscriptions in remote locations exclusively attributed to WISPs. Once this is done, we calculate the impact on GDP by relying on the coefficient estimated by Katz and Callorda (2024) through regression models that links increase in broadband penetration to economic growth.

The contribution to GDP materializes through two effects: creation of new businesses, and growth of average income per household. TRAI estimates that in 2024 there were 830,000 WISP connections which we project to reach 1.5 million in 2030. Considering that, WISP generates an increase in the number of broadband connections between 1.98% in 2024 to 1.61% in 2030. If we apply to that growth in the number of connections the coefficient of impact on GDP from Katz and Callorda (2024), we have a total economic impact of WISP from US\$ 13 billion in 2024 to US\$ 19 billion in 2030. To that number we have to subtract the direct impact (revenues) and also consider that a fraction of those connections would also exist with other technologies. For the 2.4 GHz and 5 GHz band we assume that share of these technologies is 50%, and consequently 50% would be met by WISPs. All in all, we expect a GDP contribution of \$ 6.3 billion in 2023, increasing to \$ 7.4 billion in 2027 (see Table 3-23).

Table 3-23. India: Estimation of GDP Contribution derived from reducing the digital divide (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
WISP subscribers	830,000	882,730	938,809	998,452	1,061,883	1,129,344	1,201,091
Households with Fixed Broadband	41,830,000	46,465,760	51,615,272	57,335,472	63,689,607	70,747,931	74,668,208
Households	299,178,884	304,146,194	309,195,977	314,329,602	319,548,461	324,853,970	330,247,567
Adoption WISP	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.4%
Adoption broadband	13.98%	15.28%	16.69%	18.24%	19.93%	21.78%	22.61%
WISP additional	1.98%	1.90%	1.82%	1.74%	1.67%	1.60%	1.61%
Impact of fixed broadband adoption in GDP	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%
GDP (US\$ billion)	\$ 3,937	\$ 4,340	\$ 4,790	\$ 5,287	\$ 5,833	\$ 6,437	\$ 7,102
WISP Total impact (US\$ billion)	\$ 12.66	\$ 13.36	\$ 14.11	\$ 14.92	\$ 15.76	\$ 16.65	\$ 18.51
WISP Revenues (US\$ billion)	\$ 0.06	\$ 0.06	\$ 0.07	\$ 0.07	\$ 0.08	\$ 0.08	\$ 0.09
Share that exist because WISP	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
WISP spillovers on GDP (US\$ million)	\$ 6,298	\$ 6,647	\$ 7,023	\$ 7,422	\$ 7,840	\$ 8,282	\$ 9,211

Sources: TRAI; IMF; Telecom Advisory Services analysis

The allocation of the full 6 GHz band to unlicensed use would allow WISPs to increase their subscriber base within their same coverage footprint. We follow a conservative approach and consider that the expanded coverage yielded an additional 2%, adjusted by the share of the households that adopt Wi-Fi 6E. In addition, an increase of the user base would allow service providers to lower their operating costs. Thus, by assuming stability in prices, affordability would increase as GDP per capita grows. For conservative purposes we only consider 50% of

those affected, given that the other 50% of households could also be connected using an alternative technology, such as satellite. All in all, we estimate an overall increase in WISP connections due to use of the entire 6 GHz of 8,399 connections in 2024 growing to 22,746 connections in 2030, contributing to an increase of approximately 0.10% of the national broadband penetration. Considering the impact coefficient of broadband on the economy, this increase will yield US\$ 4.9billion of GDP contribution in 2030 (See Table 3-24).

Table 3-24. India: GDP Contribution derived from reducing the digital divide due to 6 GHz (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
New subscribers due to expanded coverage (%)	2%	2%	2%	2%	2%	2%	2%
New subscribers due to expanded coverage	8,399	11,640	14,365	16,734	18,865	20,847	22,746
GDP per capita	\$ 2,731	\$ 2,984	\$ 3,265	\$ 3,573	\$ 3,911	\$ 4,281	\$ 4,687
Growth in GDP per capita	9.22%	9.26%	9.42%	9.46%	9.44%	9.47%	9.47%
New WISP adoption after price decrease (% households)	0.38%	0.40%	0.42%	0.44%	0.46%	0.48%	0.50%
Traffic through Wi-Fi 6E (%)	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Increase in WISP connections due to lower prices (households that buy the service)	152,442	212,173	266,496	311,757	350,738	389,015	424,447
Share that exist because WISP	70.00%	70.00%	70.00%	70.00%	70.00%	70.00%	70.00%
Total Increase in WISP connections	115,108	160,161	200,913	234,964	264,382	293,158	319,859
Increase in national broadband penetration	0.04%	0.05%	0.06%	0.07%	0.08%	0.09%	0.10%
Impact of fixed broadband adoption in GDP	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%	16.20%
Increase in the GDP due to the new broadband adoption (% GDP)	0.04%	0.06%	0.06%	0.07%	0.07%	0.07%	0.07%
Total impact in GDP (US\$ million)	\$ 1,755	\$ 2,423	\$ 3,020	\$ 3,510	\$ 3,923	\$ 4,321	\$ 4,929

Sources: World Bank; TRAI; Katz and Callorda (2024); Telecom Advisory Services analysis

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To sum up, as a key component of residential infrastructure, Wi-Fi drives economic contribution at multiples levels:

- Wi-Fi devices operating in the 6 GHz band, provide faster than mobile broadband device interfacing, driving a total consumer surplus of \$57 million in 2024 increasing to \$4,126 million in 2034.
- In the absence of Wi-Fi, users of devices lacking an Ethernet port, such as smartphones and tablets, would have to depend on the cellular network to gain Internet access (although we acknowledge that adaptors exist that allow hooking up these devices to the wired Ethernet). If this traffic had to be transported by cellular networks, it would result in a consumer saving of \$2.9 billion in 2024, reaching US\$8.9 billion in 2034.
- Wi-Fi represents an infrastructure that supports in-home device connectivity avoiding the need to deploy Ethernet cable in each room, an expensive proposition. Considering the additional annual value of incremental households that avoid deploying Ethernet wiring, results in consumer savings of US\$ 761 million in 2024.
- Wi-Fi enables the adoption of a multiplicity of devices that propel consumer benefit (such as alarm systems). The consumer benefit associated with the adoption of devices operating in all Wi-Fi standards in 2.4 GHz, 5 GHz, and 6 GHz bands yields a consumer surplus equivalent to US\$ 525 million in 2024 and US\$ 1.9 billion in 2034.
- Wi-Fi is an integral component of wireless ISPs (called WISPs) that provide broadband connectivity for unserved communities. The contribution to GDP of wireless broadband access materializes through multiple effects: creation of new businesses, increasing productivity of existing enterprises, and growth of average income per household, reaching US\$ 8 billion in 2024 and US\$ 25 billion in 2034.

3.3. Enterprise Wi-Fi

Beyond the impact on consumers, Wi-Fi also contributes significant economic value in the Indian enterprise segment. This section provides estimates in seven areas:

- Benefits derived from an increase in average speed: the improvements of average download speed for enterprises as a result of using Wi-Fi within in-building connectivity.
- Benefits derived from reduced latency: The total improvements of latency from Wi-Fi, principally from Wi-Fi 6E, for enterprises.
- Savings in business Internet traffic transmitted through Wi-Fi: Total Wi-Fi enterprise savings results from wireless traffic that is routed through Wi-Fi access points.
- Avoidance of campus and enterprise facilities inside wiring.
- Enhanced IoT deployment: the spillover impact of Wi-Fi enabled IoT terminals.
- Deployment of Augmented Reality/Virtual Reality solutions: the adoption of AR/VR among Indian business has a spillover effect on productivity, thereby contributing to the growth of GDP.
- Energy productivity: the total energy consumption reduction from Wi-Fi is projected to escalate dramatically.
- Deployment of Augmented Reality/Virtual Reality solutions.

3.3.1. Benefits derived from an increase in average speed

Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased overall efficiency and innovation. This contribution is measured in terms of economic growth.

As described in the area of consumer benefit of Wi-Fi impact operating in the 2.4 GHz and 5 GHz bands, we assume, for conservative purpose, no impact, given Wi-Fi technological limitations. These constraints create a discrepancy between the fixed broadband purchased speed and the actual speed delivered at the device level. As a result, while the theoretical maximum speeds of Wi-Fi might be high, real-world factors such as network congestion, signal interference, and device capabilities mean that the actual speeds experienced by users are often lower, thereby affecting the overall performance and reliability of Wi-Fi connections.

On the other hand, household residences benefit from Wi-Fi 6E additional speeds if the fixed line acquired is higher than 150 Mbps and the router is based on that standard. In the present section we utilize the speeds estimates in section 3.1.2 to analyze the benefit on GDP. The economic benefit of higher internet speeds is addressed in the enterprise section because we assume that the economic impact primarily stems from increased labor productivity and overall efficiency in business locations. Enhanced internet speeds facilitate more efficient remote work, reduced downtime, and more efficient communication and collaboration. As a result, the productivity gains experienced by workers translate into broader economic benefits, which are then reflected in the enterprise sector's performance and growth.

To translate the increase in speed with Wi-Fi 6E into GDP growth, we rely on the results of an econometric model linking broadband speed with GDP. This model quantifies the relationship between quality improvement in fixed broadband with its economic effect. In this way, after calculating the difference in average download speed attributed to Wi-Fi 6E, the additional contribution to the Indian GDP will yield \$ 87 billion in 2030 (see table 3-25).

Table 3-25. India: Estimation of speed differential due to Wi-Fi 6E (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Mean speed with no Wi-Fi 6E (Mbps)	90.61	102.95	115.84	129.66	143.01	155.55	167
Mean speed with Wi-Fi 6E (Mbps)	95.92	113.20	134.43	160.51	191.30	227.98	277
Speed increase due to Wi-Fi 6E (%)	0.06	0.10	0.16	0.24	0.34	0.47	66%
Impact speed on GDP	1.96%	1.96%	1.96%	1.96%	1.96%	1.96%	1.96%
Increase in GDP	0.11%	0.19%	0.31%	0.47%	0.66%	0.91%	1.29%
Traffic through Wi-Fi 6E (%)	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
GDP increase (\$ million)	\$2,284	\$5,571	\$11,500	\$20,616	\$34,225	\$54,100	\$86,601

Sources: Ookla Speedtest; Telecom Advisory Services analysis

3.3.2. Benefits derived from reduced latency

Reducing latency enhances the efficiency and responsiveness of various applications and services. Lower latency improves the performance of real-time applications such as telemedicine, online education, and remote work, facilitating better access to essential services and reducing disparities caused by geographical barriers. In the economic sector, reduced latency boosts productivity by enabling faster and more reliable data transmission, critical for industries like finance, manufacturing, and logistics. Overall, minimizing latency fosters greater innovation, economic growth, and social inclusion by ensuring that technology can meet the demands of an increasingly digital and interconnected world. In the present section we estimate that impact.

In this section, we measure the latency gains from using Wi-Fi rather than relying on mobile broadband. We estimate, using historical Ookla Speedtest data, that in India average Wi-Fi latency will decrease from 6.12 Ms in 2024 to 4.28 Ms in 2030. On the other hand, mobile networks latency will also drop from 34.19 Ms to 27.70 Ms between 2024 and 2030. Considering that the percentage of household traffic going through Wi-Fi will increase from 73% in 2024 to 88% in 2030, we forecast a latency reduction due to Wi-Fi ranging from 60% to 74%.

To estimate the economic impact of latency reduction, we developed an econometric model linking the improvement in speed and latency to GDP. According to the model, we estimate that the increase in GDP due to reduced latency is 4.50%. Considering that the traffic through in the 2.4 GHz and 5 GHz bands decreases over the years, the resulting GDP contribution due to latency reduction is US\$ 53 billion in 2024, declining to US\$ 26 billion in 2027 (see table 3-26).

Table 3-26. India Estimation of latency reduction due 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Average Latency using Wi-Fi (Ms)	6.12	5.77	5.44	5.12	4.82	4.55	4.28
Average Latency using mobile network (Ms)	34.19	33.01	31.87	30.77	29.71	28.69	27.70
Percentage of household traffic that goes through Wi-Fi	73%	76%	79%	81%	84%	86%	88%
Average Latency with no Wi-Fi (Ms)	34	33	32	31	30	29	28
Average Latency using Wi-Fi (Ms)	14	12	11	10	9	8	7
Latency reduction (%)	-60%	-63%	-65%	-68%	-70%	-72%	-74%
Impact of latency in GDP	4.50%	4.50%	4.50%	4.50%	4.50%	4.50%	4.50%
Increase in GDP	2.71%	2.83%	2.95%	3.06%	3.16%	3.25%	3.33%
GDP (US\$ billion)	\$ 3,937	\$ 4,340	\$ 4,790	\$ 5,287	\$ 5,833	\$ 6,437	\$ 7,102
Traffic through Wi-Fi 6 or less	49%	34%	23%	16%	11%	8%	5%
GDP increase (US\$ million)	\$ 52,669	\$ 41,875	\$ 33,182	\$ 26,184	\$ 20,573	\$ 16,109	\$ 12,574

Sources: Ookla Speedtest; IMF; Telecom Advisory Services analysis

When comparing Wi-Fi in the 6 GHz band versus 2.4 GHz and 5 GHz, latency diminishes by 40% (see detail calculation in Appendix C). This significant reduction translates to enhanced performance and user experience across various applications and services. Table 3-21 analyzes the economic impact of this latency reduction from 2024 to 2030. The analysis begins by estimating the share of traffic that could be affected by that improvement (i.e., the traffic through the 6 GHz band, considering the share of household traffic that goes through Wi-Fi). When considering all connections, the overall latency reduction due to Wi-Fi 6E varies, starting at 15% in 2024, increasing to 33% in 2030. By relying on the same methodology as in the previous section, we obtain that the corresponding increase is US\$ 26.3 billion in 2024, rising to \$ 106.1 billion in 2030 (see table 3-27).

Table 3-27. India: Estimation of latency differential due to the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Percentage of household traffic that goes through Wi-Fi	73.25%	76.21%	78.94%	81.44%	83.70%	85.73%	87.54%
Traffic through Wi-Fi 6E	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Latency reduction due to Wi-Fi 6E	40.00%	40.00%	40.00%	40.00%	40.00%	40.00%	40.00%
Latency reduction due to Wi-Fi 6E (Considering all connections)	15%	20%	24%	27%	30%	32%	33%
Impact latency on GDP	4.50%	4.50%	4.50%	4.50%	4.50%	4.50%	4.50%
Increase in GDP	0.67%	0.91%	1.09%	1.23%	1.34%	1.43%	1.49%
GDP increase (\$ million)	\$26,284	\$39,282	\$52,112	\$64,993	\$78,122	\$91,740	\$106,050

Sources: Ookla Speedtest; IMF; Telecom Advisory Services analysis

3.3.3. Savings in business Internet traffic transmitted through Wi-Fi

As expected, Indian corporations generate substantial wireless Internet traffic. Using the last Cisco estimate we project 20 billion GB of internet traffic for 2024. Wi-Fi enterprise savings results from wireless traffic that is routed through Wi-Fi access points rather than cellular networks. Considering Cisco projections, we estimate that total business Internet traffic will reach 72 billion GB in 2030, of which 17 billion GB will be transported through Wi-Fi access points. Considering the average price per GB transported by cellular carriers, savings from Wi-Fi will reach US\$ 1 billion in 2030, assuming the amount of data consumed would stay constant³⁶ (see table 3-28).

Table 3-28. India: Savings in business wireless traffic (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Share of Business Internet Traffic by Wi-Fi	27.83%	27.14%	26.47%	25.82%	25.18%	24.56%	23.95%
Total Business Internet Traffic (billion GB)	20.430	25.199	31.082	38.337	47.286	58.323	71.937
Total GB Wi-Fi enterprise traffic (billion GB)	5.686	6.840	8.227	9.897	11.906	14.322	17.228
Average Price per GB	\$0.10	\$0.09	\$0.09	\$0.08	\$0.07	\$0.07	\$0.06
Economic Impact (US\$ billion)	\$0.584	\$0.644	\$0.710	\$0.782	\$0.862	\$0.951	\$1.048

Sources: Cisco; Websites of cellular operators; Telecom Advisory Services analysis

The deployment of the latest enterprise applications will generate an exponential growth in data traffic that will be handled by devices operating in unlicensed spectrum, through the combination of the existing bands and the 6 GHz band using Wi-Fi 6E. In 2019, an updated Cisco traffic forecast based on the explosion of IoT and AR/VR applications, among other

³⁶ We acknowledge that enterprises are likely to negotiate wireless rates lower than those offered in the consumer market; however, data in this area is not available.

factors, increased the estimates of future total business Internet traffic. We assume that part of the growth was driven by “natural” growth (that is to say, the extrapolation of historical growth rate by averaging the growth rate between 2018 and 2019 and between 2017 and 2018), and another portion was triggered by Wi-Fi traffic stimulated by changes in 6 GHz using Wi-Fi 6E. The sum of the difference due to broader Wi-Fi traffic between will reach US\$ 498 million in 2030 (see Table 3-29).

Table 3-29. India: Savings in business wireless traffic due to 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Share of Business Internet Traffic by Wi-Fi	29.61%	29.42%	29.22%	29.03%	28.84%	28.65%	28.47%
Total Business Internet Traffic (billion GB)	50.468	68.925	94.132	128.558	175.573	239.782	327.473
Total GB Wi-Fi enterprise traffic (billion GB)	14.943	20.275	27.509	37.323	50.640	68.707	93.221
Total (US\$ billion)	\$1.534	\$1.908	\$2.372	\$2.950	\$3.668	\$4.561	\$5.671
Difference between the 2 estimations (US\$ million)	\$950.598	\$1,264.312	\$1,662.822	\$2,167.631	\$2,805.569	\$3,610.091	\$4,622.904
Difference because natural growth (US\$ million)	\$848.122	\$1,128.017	\$1,483.567	\$1,933.958	\$2,503.125	\$3,220.918	\$4,124.548
Difference due to Wi-Fi 6E (US\$ million)	\$102.476	\$136.295	\$179.255	\$233.674	\$302.445	\$389.173	\$498.356

Sources: Cisco; Telecom Advisory Services analysis

3.3.4. Avoidance of enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we take the total number of business establishments are equipped with Wi-Fi access points and multiply this value by a standard cost of deploying a CAT 6 network (US\$ 537 per bundling). We only consider the savings due to the yearly increase in the number of connections, so we estimate a producer surplus of US\$ 34 million in 2024, and US\$ 39 million in 2030 (See Table 3-30).

Table 3-30. India: Savings in business wiring CAPEX (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Wiring Cost (*)	\$537.22	\$537.22	\$537.22	\$537.22	\$537.22	\$537.22	\$537.22
Number of establishments	2,663,016	2,727,559	2,793,667	2,861,377	2,930,728	3,001,760	3,074,513
Establishments with Wi-Fi (%)	100%	100%	100%	100%	100%	100%	100%
Establishments with Wi-Fi	2,663,016	2,727,559	2,793,667	2,861,377	2,930,728	3,001,760	3,074,513
Inside Wiring Costs (US\$ million)	\$1,431	\$1,465	\$1,501	\$1,537	\$1,574	\$1,613	\$1,652
Inside Wiring Costs, Yearly increase (US\$ million)	\$34	\$35	\$36	\$36	\$37	\$38	\$39

(*) Wiring costs assumed to be stable in the future

Sources: Statista; World Bank; Telecom Advisory Services analysis

3.3.5. Enhanced IoT Deployment

IoT adoption has a contribution to GDP growth through the multiplicity of use cases that improve efficiency in processes such as preventive maintenance, production monitoring and the like. To estimate this, we rely on a coefficient of GDP impact calculated through an

aggregate simple production function which estimates that a 10% rise in M2M connections results in annual increases in GDP of 0.3%³⁷.

The key methodological objective to apply the impact coefficient is to determine what is the increase year-on-year in Wi-Fi enabled IoT connections. Unfortunately, we lack this indicator, although we have three related ones:

- The difference between two forecasts of M2M connections from the same source (GSMA Intelligence, 2024)
- The difference in yearly forecasts of M2M connections (GSMA Intelligence)
- The percent of IoT installed base that is supported by Wi-Fi, which is 31% (IoT Analytics (2023)). In addition, this source indicates that the CAGR for the Wi-Fi IoT connected devices is expected to be 16% between 2022 and 2027.³⁸

The number of M2M is an adequate proxy for the level of development of the IoT market. M2M terminals are often isolated, stand-alone networked equipment. IoT systems take M2M to the next level, bringing together disparate systems into one large, connected ecosystem. While not totally equivalent, the M2M variable provides a fairly good quantitative indicator.

Starting with a 2024 installed base of 16 million M2M connections, we estimated that higher Wi-Fi speeds explain the growth from 14 million connections based on previous M2M estimations for 2023 (a 15.76% increase). According to this metric, we are assuming that the percentage change in Wi-Fi enabled IoT (or in this case M2M) devices is related to the difference between both forecasts. A second approach may be to consider the yearly difference between the number of M2M connections for India, considering the growth rate between M2M connections projected for 2024 against those from the 2023 forecast. A third alternative approach is available, relying on IoT Analytics projections of a worldwide CAGR for Wi-Fi M2M devices of 16%. That alternative has several problems: First, it is a global rather than local value. Second, we lack the base of total IoT terminals against which we can calculate the number of terminals that are Wi-Fi enabled. We decided to rely on the first approach, although, cognizant of its limitations, we will provide the results of the second and the third approximation to demonstrate that the first one provides a more conservative Wi-Fi value estimate.

Regarding the first approach, we calculate the incremental number of devices between both estimates from GSMA Intelligence, apply the coefficient of GDP impact of 0.3%. In this way, the impact on GDP, expressed as a percentage, grows from 0.47% in 2024 to 1.07% in 2027. The annual economic impact, calculated as a product of GDP impact and GDP itself, ranges from \$18.6 billion in 2024 to \$56.7 billion in 2027 (see table 3-31).

³⁷ See Frontier Economics (2018)

³⁸ Retrieved in: <https://iot-analytics.com/number-connected-iot-devices/>

Table 3-31. India: GDP Contribution of IoT Deployment due to Wi-Fi (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Connections, M2M (2021 est.)	13,962,426	12,907,091	13,828,451	14,724,839	15,609,353	16,487,881	17,373,549
Connections, M2M (2024 est.)	16,162,329	17,520,618	18,771,310	19,988,104	21,188,780	22,381,330	23,583,572
Incremental	15.76%	35.74%	35.74%	35.74%	35.74%	35.74%	35.74%
Impact of M2M Growth on GDP	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%
Impact on GDP (%)	0.47%	1.07%	1.07%	1.07%	1.07%	1.07%	1.07%
GDP (US\$ billion)	\$3,937	\$4,340	\$4,790	\$5,287	\$5,833	\$6,437	\$7,102
Annual Impact (US\$ million)	\$18,609	\$46,537	\$51,362	\$56,694	\$62,553	\$69,022	\$76,159

Sources: GSMA Intelligence; Frontier Economics; IMF; Telecom Advisory Services analysis

In table 3-31 we estimated the total impact of M2M connections, considering all categories of Wi-Fi. Now, we break down the effect for Wi-Fi operating in the 2.4 GHz and 5 GHz bands. To account for the differential impact by frequency bands, we considered a decline in traffic as a result of diminishing impact of Wi-Fi 6 or lower standards. This results in a decrease in GDP contribution from US\$ 9.2 billion in 2024 to US\$ 4 billion in 2030 (See Table 3-32).

Table 3-32. India: GDP Contribution of IoT Deployment in 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Connections, M2M (2021 est.)	13,962,426	12,907,091	13,828,451	14,724,839	15,609,353	16,487,881	17,373,549
Connections, M2M (2024 est.)	16,162,329	17,520,618	18,771,310	19,988,104	21,188,780	22,381,330	23,583,572
Incremental	15.76%	35.74%	35.74%	35.74%	35.74%	35.74%	35.74%
Impact of M2M Growth on GDP	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%
Impact on GDP (%)	0.47%	1.07%	1.07%	1.07%	1.07%	1.07%	1.07%
GDP (\$ billion)	\$3,937	\$4,340	\$4,790	\$5,287	\$5,833	\$6,437	\$7,102
Annual Impact (US\$ billion)	\$18,609	\$46,537	\$51,362	\$56,694	\$62,553	\$69,022	\$76,159
Traffic through Wi-Fi 6 or lower	49.40%	34.07%	23.49%	16.20%	11.17%	7.70%	5.31%
Impact (US\$ million)	\$9,194	\$15,854	\$12,066	\$9,184	\$6,988	\$5,317	\$4,046

Sources: GSMA Intelligence; Frontier Economics; IMF; Telecom Advisory Services analysis

For estimating the effect in the 6 GHz band, we first break down the effect for Wi-Fi 6E using the 6 GHz band. We estimate that the use of Wi-Fi 6E along all Wi-Fi categories varies from 50.60% in 2024 to 94.69% in 2030, with its impact ranging from US\$ 9.4 billion in 2024 to US\$ 72 billion in 2030 (see Table 3-33).

Table 3-33. India: GDP Contribution of IoT Deployment Boost caused by 6 GHz (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Wi-Fi 6E share (%)	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Impact (US\$ million)	\$9,416	\$30,683	\$39,296	\$47,510	\$55,565	\$63,705	\$72,114

Sources: GSMA Intelligence; Frontier Economics; IMF; Telecom Advisory Services analysis

3.3.6. Deployment of Augmented Reality/Virtual Reality solutions

The adoption of AR/VR among Indian businesses has a spillover effect on productivity, thereby contributing to the growth of GDP. Estimating spillover effects of AR/VR is not a trivial exercise considering the embryonic adoption of some of these use cases. Since the objective is to estimate the spillover effect of AR/VR sales by Indian firms in the domestic market, we will take as points of departure the estimate by PwC of the total GDP contribution of AR/VR, and the sales of AR/VR components as estimated by Statista. These two parameters allow estimating the indirect (spillover) contribution of AR/VR to the Indian economy for the period under analysis. Starting with the total estimated impact for AR/VR provided by PwC, we then subtract the portion attributable to Wi-Fi 6 or lower technologies. Next, we deduct the direct impact of AR/VR, which yields the total indirect impact figure.

To maintain a conservative approach, we assume that the indirect impact does not exceed the direct impact. If we do not consider this restriction, the indirect impact of AR/VR is projected to be \$ 3,343 million in 2024, to \$ 15,281 million in 2030. But if we apply the restriction, the indirect impact could as high be the same as the direct impact, the contribution in million US dollars is projected to be \$ 244 million in 2024, to \$ 286 million in 2030 (See Table 3-34).

Table 3-34. India: GDP contribution resulting from AR/VR spillovers (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Spending in AR/VR - Hardware (\$ billion)	\$0.24	\$0.26	\$0.29	\$0.31	\$0.34	\$0.38	\$0.40
Spending in AR/VR - Software, Contents, Services (\$ billion)	\$0.55	\$0.61	\$0.66	\$0.73	\$0.80	\$0.88	\$0.94
Total Spending in AR/VR (\$ billion)	\$0.79	\$0.87	\$0.95	\$1.04	\$1.14	\$1.26	\$1.34
Share attributable to Wi-Fi (Wi-Fi 6 or less)	30.88%	29.32%	27.76%	26.21%	24.61%	22.97%	21.28%
Direct Impact Wi-Fi 6 or less (\$ billion), spending	\$0.24	\$0.25	\$0.26	\$0.27	\$0.28	\$0.29	\$0.29
Total Impact on GDP (\$ billion)	\$11.62	\$18.01	\$23.80	\$31.50	\$41.67	\$55.20	\$73.14
Share attributable to Wi-Fi (Wi-Fi 6 or less)	30.88%	29.32%	27.76%	26.21%	24.61%	22.97%	21.28%
Total Impact (Wi-Fi 6 or less)	\$3.59	\$5.28	\$6.61	\$8.26	\$10.25	\$12.68	\$15.57
Indirect impact (\$ million)	\$3,343	\$5,026	\$6,345	\$7,982	\$9,972	\$12,391	\$15,281
Indirect / direct impact	13.72	19.79	24.05	29.21	35.41	42.95	53.51
Max indirect/direct	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Annual Indirect Impact (\$ million)	\$243.65	\$253.90	\$263.83	\$273.30	\$281.64	\$288.48	\$285.57

Sources: Statista; PwC; Telecom Advisory Services analysis

Higher throughput enabled by the allocation of the 6 GHz band is expected to spur further adoption and use of AR/VR among enterprises, hence increasing the associated spillover effects. By relying on the ratio built from 5 GHz and 6 GHz AR/VR related products, we were able to isolate the specific economic contribution of the new spectrum allocation.

Following a similar procedure as the one described in the section above, spillovers from AR/VR attributed to the 6 GHz band will account for US\$ 282 million in 2024 and are expected to increase by 2030 to US\$ 608 million (see Table 3-35).

Table 3-35. India: GDP contribution resulting from AR/VR spillovers due to the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Impact Wi-Fi 6E/Wi-Fi 6 or less	115.66%	127.12%	139.86%	154.12%	170.62%	189.95%	212.88%
Impact of the 6 GHz band (US\$ million)	\$281.80	\$322.74	\$369.00	\$421.20	\$480.54	\$547.96	\$607.93

Sources: Statista; PwC; Telecom Advisory Services analysis

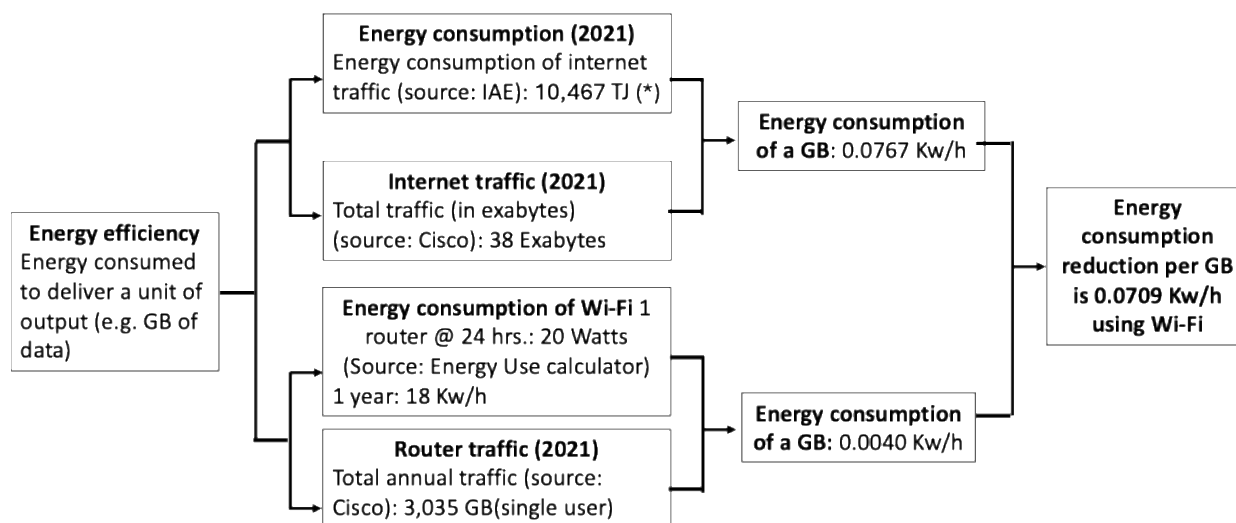
3.3.7. Wi-Fi and energy efficiency

Wi-Fi technology offers a significant advantage over alternative technologies in terms of energy efficiency.³⁹ Unlike other technologies that may consume more energy for data transmission, Wi-Fi is designed to provide high-speed internet access while minimizing energy usage. This efficiency is crucial in an era where the volume of internet traffic is exponentially increasing, necessitating solutions that can handle large data loads without proportional increases in energy consumption.

The present analysis demonstrates the energy savings achieved through the use of Wi-Fi (see figure 3-1).

³⁹ See Kroon, P., Godlovitch, I. and Plückebaum, Th. (2023). *Sustainability benefits of 6 GHz Spectrum Policy*. Bad Honnef: WIK Consult.

Figure 3-1. Comparative analysis of energy consumption per GB



(*) 1 Terajoule = 277778 Kw/h

Sources: International Energy Agency; Cisco; Telecom Advisory Services analysis

In 2023, the total energy consumption of internet traffic in India is estimated at 10,467 TJ, translating to 2,907,533,357 kW/h. With a total internet traffic of 480 Exabytes in 2024, or 479,660 million GB, the energy consumption per GB stands at 0.006 kW/h. When considering Wi-Fi, the annual energy consumption is significantly lower, at 18 kW/h, resulting in an energy consumption per GB of just 0.003 kW/h in 2024, decreasing further to 0.001 kW/h by 2030 (due to the increase in data usage).

The cost reduction per GB, calculated as the difference between the energy consumption per GB of internet traffic and Wi-Fi, indicates substantial savings, accounting for 0.0028 kW/h in 2024. With the number of households using internet and Wi-Fi expected to grow, the total energy consumption reduction is projected to reach 237 million kW/h in 2027. This reduction underscores the critical role of Wi-Fi in enhancing energy productivity and highlights the significant economic and environmental benefits of adopting energy-efficient internet technologies (see Table 3-36).

Table 3-36. India: Wi-Fi energy saving (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Energy consumption of internet traffic (TJ)	10,467	10,467	10,467	10,467	10,467	10,467	10,467
Energy consumption of internet traffic (million Kw/h)	2,907.533	2,907.533	2,907.533	2,907.533	2,907.533	2,907.533	2,907.533
Total traffic (Exabytes)	480	685	880	1,132	1,454	1,869	2,402
Total traffic (million GB)	479,660.737	684,987.421	880,386.820	1,131,525.818	1,454,304.686	1,869,159.400	2,402,355.502
Energy consumption of a GB (Kw/h)	0.0061	0.0042	0.0033	0.0026	0.0020	0.0016	0.0012
Energy consumption of Wi-Fi (1 year) Kw/h	18	18	18	18	19	20	21
Total annual traffic (GB per user)	5,302	6,386	7,691	9,263	11,156	13,436	16,182
Energy consumption of a GB (Kw/h) with Wi-Fi	0.0033	0.0027	0.0023	0.0019	0.0017	0.0015	0.0013
Cost Reduction per GB	0.0028	0.0015	0.0010	0.0007	0.0003	0.0001	0.0000
Households with internet and Wi-Fi	24,972,510	28,669,374	32,878,928	37,669,405	43,117,864	49,311,308	53,537,105
Energy consumption reduction (million Kw/h)	365.072	274.794	259.065	236.605	163.132	68.047	0

Sources: IAE; CISCO; Telecom Advisory Services analysis

* * * * *

In summary, Wi-Fi also contributes significant economic value in the US enterprise segment:

- Benefits derived from an increase in average speed. The improvements of average download speed for enterprises as a result of using Wi-Fi within in-building connectivity are estimated at US\$ 2,284 million in 2024 and projected to reach US\$ 266 billion in 2034.
- Benefits derived from reduced latency. The total improvements of latency from Wi-Fi for enterprises are estimated at US\$ 26.3 billion in 2024, reaching US\$ 174 billion in 2034.
- Savings in business Internet traffic transmitted through Wi-Fi. Total Wi-Fi enterprise savings results from wireless traffic that is routed through Wi-Fi access points is estimated to US\$ 686 million in 2024 and will amount to US\$ 2.8 billion in 2034.
- Avoidance of campus and enterprise facilities inside wiring: Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points and consider only the savings due to the yearly increase in the number of connections, yielding a producer surplus of US\$ 34 million in 2024, and US\$ 43 million in 2034.
- Enhanced IoT deployment. It is conservatively estimated that the spillover impact of Wi-Fi enabled IoT terminals is estimated at US\$ 17.8 billion in 2024 and will grow to reach US\$ 103.6 billion in 2034.
- Deployment of Augmented Reality/Virtual Reality solutions: the adoption of AR/VR among local business has a spillover effect on productivity, thereby contributing to the growth of GDP. Total spillovers driven by successive generation of Wi-Fi standards are estimated to reach US\$ 365 million in 2034.
- Wi-Fi technology offers a significant advantage over alternative technologies in terms of energy efficiency. Considering the number of Indian households accessing the internet and Wi-Fi residences expected to grow over the following years, the total energy consumption reduction is projected to reach 237 million kW/h in 2027.

3.4. Unlicensed spectrum and Internet Service Providers

In addition to the economic value generated by the sources analyzed above, Wi-Fi will also contribute to either producer surplus or GDP of Internet Service Providers. This section will assess the economic value within three sources:

- Producer surplus of cellular operators resulting from CAPEX savings incurred in network deployment and operations
- Revenues of Wi-Fi carriers offering service in public spaces
- Revenues of Wireless ISPs (this effect differs from the GDP impact of WISPs as a result of their deployment in rural and isolated areas, assessed in section 3.5)

3.4.1. Cellular network CAPEX savings from off-loading traffic to Wi-Fi

The value of cellular off-loading decreases the total cost of ownership by using Wi-Fi to complement cellular networks, thereby limiting the need for future capacity increases. While the economic advantage of off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are considerably less expensive than cellular network equipment with similar capacity.

Based on prior studies, we estimate that cellular networks CAPEX savings by relying on Wi-Fi for off-loading traffic is 8.10% in 2024, growing to 8.44% in 2030⁴⁰ by relying on the 6 GHz band. This amounts to savings ranging from \$ 535 million in 2024, to \$ 753 million in 2030 (See Table 3-37).

Table 3-37. India: Cellular network CAPEX savings by off-loading traffic to Wi-Fi using Wi-Fi 6E (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total mobile CAPEX (US\$ million)	\$6,610	\$6,880	\$7,309	\$7,862	\$8,282	\$8,590	\$8,919
Share of traffic off-load	8.10%	8.13%	8.18%	8.24%	8.31%	8.38%	8.44%
Total CAPEX savings by traffic off-loading (US\$ million)	\$535	\$559	\$598	\$648	\$688	\$720	\$753

Sources: GSMA Intelligence; Telecom Advisory Services analysis

3.4.2. Revenues of Wi-Fi based Public Internet Service Providers

The economic value generated by Wi-Fi carriers is calculated from the sum of revenues collected by public Wi-Fi-based service providers operating within transit hubs and other public venues. These revenues are being considered as contributions to the Indian GDP.

To estimate the total revenues of these providers, we start by calculating the number of commercial Wi-Fi hotspots in India. Relying on CISCO data, in 2024 there were approximately 220,000 commercial Wi-Fi hotspots, which are estimated to increase to 380,000 in 2030. Based on revenue figures from financial statements and the number of hotspots deployed by a publicly traded company in the U.S. (adjusted by PPP to the Indian case), we estimate an average revenue figure per hotspot. By extrapolating that amount to the overall number of paid Wi-Fi hotspots in the country, we estimate total revenues generated by this sector in India to be US\$ 33 million in 2024, gradually increasing to US\$ 57million in 2030 (Table 3-38).

Table 3-38. India: Revenues of Wi-Fi carriers (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Pay Wi-Fi hotspots (million)	0.22	0.24	0.26	0.29	0.31	0.34	0.38
Revenue per hotspot	\$151	\$151	\$151	\$151	\$151	\$151	\$151
Revenue (million US\$)	\$33	\$36	\$40	\$43	\$48	\$52	\$57

Sources: Cisco, Wi-Fi Map; Boingo; World Bank; Telecom Advisory Services analysis

The allocation of the 6 GHz spectrum band offers an opportunity for commercial Wi-Fi carriers to enhance their business. As Wi-Fi 6E developments will allow up to 1,500 connected devices per access point, Wi-Fi carriers will have the possibility of adding more customers without quality limitations due to congestion. By considering a conservative potential increase of 40% in the number of connected devices in public venues and weighting that figure by the gradual expansion of the latest technology, we expect commercial Wi-Fi carriers using Wi-Fi 6E to increase their user base from 20% in 2024 to 38% in 2030. If the revenue per hotspot increases in the same amount, that will yield an increase in overall revenues for the sector of an additional US\$ 22 million by 2030 (Table 3-39).

⁴⁰ We estimate that traditional MNOs off-load 8% of their traffic and cable operators off-load 10% of their traffic, with the overall off-load a weighted average of these two percentages with weights based on the connection shares of these two segments of the industry.

Table 3-39. India: Revenues of Wi-Fi carriers due to Wi-Fi 6E in 6 GHz (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Potential increase in connected devices in public venues	40.00%	40.00%	40.00%	40.00%	40.00%	40.00%	40.00%
Traffic through Wi-Fi 6E (%)	51%	66%	77%	84%	89%	92%	95%
Increase in connected devices due to Wi-Fi 6E	20%	26%	31%	34%	36%	37%	38%
Revenue per hotspot if 6 GHz allocated	\$ 182	\$ 191	\$ 197	\$ 202	\$ 205	\$ 207	\$ 208
Revenue if Wi-Fi 6E allocated (million US\$)	\$6.7	\$9.6	\$12.1	\$14.6	\$16.9	\$19.2	\$21.6

Sources: Boingo; Telecom Advisory Services analysis

3.4.2. Revenues of Wi-Fi based Wireless Internet Service Providers (WISPs)

WISPs rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas of the country. TRAI estimates that Indian WISPs serve 830,000 subscribers in 2024. Based on industry growth trends, we expect the subscriber base to reach 1.2 million by 2030. Using monthly ARPU figures,⁴¹ 2024 revenues are estimated at US\$ 59 million (see table 3-40).

Table 3-40. India: WISP revenues (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Subscribers (million)	0.83	0.88	0.94	1.00	1.06	1.13	1.20
Revenues (US\$ million)	\$59.26	\$63.03	\$67.03	\$71.29	\$75.82	\$80.64	\$85.76

Sources: TRAI; Muftinternet.com; Telecom Advisory Services analysis

As described, the allocation of 6 GHz spectrum band using Wi-Fi 6E will potentially increase the WISP user base by 0.32 million subscribers in 2030, due to expanded coverage and better affordability. Assuming the same ARPU values as described above, the new subscriptions will account for an additional US\$ 22.84 million in revenues in 2030 (Table 3-41).

Table 3-41. India: WISP revenues due to 6 GHz (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
WISP annual ARPU (\$)	\$71.40	\$71.40	\$71.40	\$71.40	\$71.40	\$71.40	\$71.40
New subscribers with 6 GHz (million)	0.12	0.16	0.20	0.23	0.26	0.29	0.32
New revenue (US\$ million)	\$8.22	\$11.44	\$14.35	\$16.78	\$18.88	\$20.93	\$22.84

Sources: TRAI; Muftinternet.com; Telecom Advisory Services analysis

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Wi-Fi will also contribute to either producer surplus or GDP of Internet Service Providers. This section has assessed the economic value within three sources:

- Producer surplus of cellular operators resulting from CAPEX savings incurred in network deployment and operations. The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks. Estimated at 8.10% of total CAPEX in 2024, it amounts to US\$ 466 million, increasing to US\$ 787 million in 2034.
- Revenues of Wi-Fi carriers offering service in public spaces. Based on the revenues per site of Wi-Fi service providers, total revenues have reached US\$ 40 million in 2024, diminishing to US\$ 114 million in 2034.
- Revenues of Wireless ISPs: The WISPs relying on unlicensed bands to deliver service to their customers generate revenues totaling US\$ 67 million in 2024, increasing to \$ 139 million in 2034.

⁴¹ <https://muftinternet.com/isp-consultant-india/start-wisp-business/>

3.5. Development of the Wi-Fi Ecosystem

The economic value generated by Wi-Fi within the Wi-Fi ecosystem companies is calculated based on the following five sources:

- The producer surplus (i.e., margins) of residential Wi-Fi devices and equipment manufactured in the United States
- The producer surplus (i.e., margins) of enterprise Wi-Fi equipment manufactured in the United States
- The producer surplus of local firms providing products and services in the IoT ecosystem (hardware, software and systems integration) in the United States
- The producer surplus of local firms providing products and services in the AR/VR ecosystem (hardware, software and content) in the United States; and

3.5.1. Manufacturing of Wi-Fi devices and equipment for residential use

In section 3.4 we calculated the producer surplus attributed to residential Wi-Fi devices and equipment, relying on the Milgrom et al. (2011) assumption that consumer surplus could be approximated by producer surplus. In this section we estimate the producer surplus, which differs from the previous analysis in two areas: (i) we only consider the residential Wi-Fi devices and equipment manufactured by local firms, and (ii) we also consider the overseas revenues generated by local residential Wi-Fi devices and equipment manufacturers.

Since our focus is estimating producer surplus, the estimation begins by compiling revenues of local manufacturers for each Wi-Fi enabled product.⁴² Considering only the share of revenues generated by local manufacturers of Wi-Fi-enabled products, sales amount to US\$ 664 million in 2024, increasing to \$ 1.4 billion in 2030, due to 6 GHz enabled products. We applied the margin estimated by CSI markets (44.6%) which yields an estimated producer surplus for these products of US\$ 196 million in 2024 decreasing to US\$ 631 million in 2030 (see table 3-42)

Table 3-42. India: producer surplus from locally manufactured residential Wi-Fi devices and equipment (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total sales (US\$ million)	\$ 663.97	\$ 749.05	\$ 846.84	\$ 959.55	\$ 1,089.77	\$ 1,240.61	\$ 1,415.77
Gross margin	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%
Producer surplus (US\$ million)	\$ 296.07	\$ 334.00	\$ 377.61	\$ 427.86	\$ 485.93	\$ 553.19	\$ 631.29

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; Telecom Advisory Services analysis

We must consider that a portion of the revenues estimated above corresponds to devices operating within the Wi-Fi 6E standard operating in the 6 GHz band. According to IDC, global shipments of consumer devices linked to Wi-Fi 6E or more will represent 39.59% of the shipments from previous generations in 2027. So, the producer surplus generated by products with 2.4 GHz and 5 GHz bands was US\$ 230 million in 2024 and forecast to attain US\$ 251 million in 2030 (see table 3-43).

⁴² Calculated considering the share of local production of electronic equipment used as inputs for Indian firms according to the Indian I/O Matrix

Table 3-43. India: producer surplus from locally manufactured residential Wi-Fi devices and equipment operating in the 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Global - Total Wi-Fi 6E or more shipments (%)	22.39%	28.72%	34.42%	39.59%	45.52%	52.35%	60.20%
Total Producer Surplus (US\$ million)	\$ 296.07	\$ 334.00	\$ 377.61	\$ 427.86	\$ 485.93	\$ 553.19	\$ 631.29
Total Producer Surplus (US\$ million) Wi-Fi 6 or less	\$ 229.76	\$ 238.07	\$ 247.62	\$ 258.49	\$ 264.72	\$ 263.60	\$ 251.25

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; IDC; Telecom Advisory Services analysis

The declining trend is the result of gradual replacement of legacy equipment with Wi-Fi 6E enabled. For this reason, we need to break down revenues between devices and equipment for Wi-Fi 6E based on the breakdown of traffic projections. On this basis, we estimate that the producer surplus generated by products operating with Wi-Fi 6E in US\$ 66 million in 2024 and will increase to US\$ 380 million in 2030 (see table 3-44).

Table 3-44. India: Economic Value of Wi-Fi enabled consumer products operating in the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Global - Total Wi-Fi 6E or more shipments (%)	22.39%	28.72%	34.42%	39.59%	45.52%	52.35%	60.20%
Total Producer Surplus (US\$ million)	\$ 296.07	\$ 334.00	\$ 377.61	\$ 427.86	\$ 485.93	\$ 553.19	\$ 631.29
Wi-Fi 6E Adoption	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Producer Surplus Wi-Fi 6E Devices (US\$ million)	\$ 66.30	\$ 95.93	\$ 129.98	\$ 169.37	\$ 221.20	\$ 289.59	\$ 380.04

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; IDC; Telecom Advisory Services analysis

3.5.2. Manufacturing of enterprise Wi-Fi devices and equipment

Following a similar approach for the case of enterprise Wi-Fi devices and equipment, producer surplus attributable to Wi-Fi 6 or less is expected to account for \$ 101 million in 2024, evolving to \$ 23 million in 2030.

Table 3-45. India: producer surplus from locally manufactured enterprise Wi-Fi devices and equipment operating in the 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total sales (US\$ million)	\$230	\$260	\$294	\$333	\$378	\$430	\$491
Gross margin	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%
Traffic through Wi-Fi 6 or less (%)	49.40%	34.07%	23.49%	16.20%	11.17%	7.70%	5.31%
Total Producer Surplus (US\$ million)	\$205	\$232	\$262	\$297	\$337	\$384	\$438
Total Producer Surplus (US\$ million) Wi-Fi 6 or less	\$101	\$79	\$62	\$48	\$38	\$30	\$23

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; IDC; Telecom Advisory Services analysis

As for the case of the value attributable to the 6 GHz band, it is estimated in \$104 million in 2024, increasing to \$415 million in 2030.

Table 3-46. India: Economic Value of Wi-Fi enabled enterprise products operating in the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Global - Total Wi-Fi 6E or more shipments (%)	41.70%	53.57%	62.96%	70.58%	79.11%	88.68%	99.40%
Total Producer Surplus (US\$ million)	\$205	\$232	\$262	\$297	\$337	\$384	\$438
Wi-Fi 6E Adoption	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Producer Surplus Wi-Fi 6E Devices (US\$ million)	\$104	\$153	\$200	\$249	\$299	\$354	\$415

Sources: TechSciResearch; Valuates Reports; Mordor Intelligence; 24MarketReports; CSI Insight; IDC; Telecom Advisory Services analysis

3.5.3. Benefits of Firms in the IoT ecosystem

According to estimates from Statista, we expect total industrial 2023 IoT revenue in India to amount US\$ 23 billion in 2024. By relying on the percentage of hardware connectivity spending of AR/VR, we were able to split that figure into the two main segments: (i) hardware; and (ii) software, contents, and services. By weighting those amounts by the share of local production according to the Indian I/O matrix (56.4% for hardware, 98.3% for software and services) and the margins (44.6% and 77.5%, respectively), we estimated the overall producer surplus. However, the share attributed to 6 GHz should be subtracted from the total economic value. To do so, we estimated a natural growth rate, by subtracting the corresponding share attributed to 6 GHz spectrum according to the growth rates indicated above. Thus, we estimate a producer surplus not attributed to 6 GHz (see table 3-47).

Table 3-47. India: IoT ecosystem direct contribution (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
IoT revenue - Hardware (\$ billions)	\$7	\$8	\$9	\$11	\$13	\$15	\$17
IoT revenue - Software, Contents, Services (\$ billions)	\$16	\$19	\$22	\$26	\$30	\$35	\$41
Total Industrial IoT revenue in (billions)	\$23	\$27	\$31	\$37	\$43	\$50	\$58
Local production (%) - Hardware	56%	56%	56%	56%	56%	56%	56%
Local production (%) - Software & Services	98%	98%	98%	98%	98%	98%	98%
Margins (%) - Hardware	45%	45%	45%	45%	45%	45%	45%
Margins (%) - Software & Services	77%	77%	77%	77%	77%	77%	77%
Margins - IoT Hardware revenue	\$2	\$2	\$2	\$3	\$3	\$4	\$4
Margins - Software, contents and services IoT revenue	\$12	\$14	\$17	\$20	\$23	\$27	\$31
Producer surplus (US\$ million)	\$14,091	\$16,424	\$19,144	\$22,315	\$26,010	\$30,312	\$35,331

Sources: Statista, CSI, Telecom Advisory Services analysis

On this basis, we must limit the estimates developed in the previous analysis to the share of sales that are generated due to Wi-Fi: we estimate that value to be 31% based on IoT Analytics data.⁴³ Additionally, we should subtract the share attributed to the Wi-Fi 6 E standard. To do so, we relied on our analysis of the shares by Wi-Fi category presented in section 3.4. Thus, we estimate a producer surplus attributed to the 2.4 GHz and 5 GHz of US\$ 2.2 billion in 2024, decreasing to US\$ 582 million in 2030 (Table 3-48).

⁴³ IoT Analytics (2023). "State of IoT 2023: Number of connected IoT devices growing 16% to 16.7 billion globally", retrieved from: <https://iot-analytics.com/number-connected-iot-devices/>

Table 3-48. India: IoT ecosystem direct contribution due to 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Producer surplus (US\$ million)	\$14,091	\$16,424	\$19,144	\$22,315	\$26,010	\$30,312	\$35,331
Share Due to Wi-Fi	31%	31%	31%	31%	31%	31%	31%
Share Due to Wi-Fi 6 or less	49.40%	34.07%	23.49%	16.20%	11.17%	7.70%	5.31%
Producer surplus attributable to Wi-Fi 6 or less (\$ million)	\$2,158	\$1,735	\$1,394	\$1,121	\$901	\$724	\$582

Sources: Statista Market Insights, CSI, Telecom Advisory Services analysis

Following the previous analysis, we were able to estimate which portion of IoT producer surplus growth can be attributed to the 6 GHz band. We expect the additional IoT surplus to account for US\$ 2.2 billion in 2024 (see table 3-49).

Table 3-49. India: IoT ecosystem direct contribution due to 6 GHz (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Share Due to 6 GHz	50.60%	65.93%	76.51%	83.80%	88.83%	92.30%	94.69%
Additional surplus due to 6 GHz	\$2,210	\$3,357	\$4,541	\$5,797	\$7,162	\$8,673	\$10,371

Sources: Statista Market Insights Market Insights; CSI; Telecom Advisory Services analysis

3.5.4. Benefits of firms in the AR/VR ecosystem

Following an approach similar to the one used for estimating the IoT contribution, we can calculate the direct contribution of the AR/VR ecosystem to the Indian economy. Starting with the local spending in AR/VR by category (hardware, software, and contents), and weighting those figures by the respective shares of local production and margins, we were able to estimate the total producer surplus (see Table 3-50).

Table 3-50. India: AR/VR ecosystem direct contribution (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Spending in AR/VR - Hardware (US\$ billion)	\$0.24	\$0.26	\$0.29	\$0.31	\$0.34	\$0.38	\$0.40
Spending in AR/VR - Software, Contents, Services (US\$ billion)	\$0.55	\$0.61	\$0.66	\$0.73	\$0.80	\$0.88	\$0.94
Total Spending in AV/VR (US\$ billion)	\$0.79	\$0.87	\$0.95	\$1.04	\$1.14	\$1.26	\$1.34
Share of local production - Hardware	56.44%	56.44%	56.44%	56.44%	56.44%	56.44%	56.44%
Share of local production - Software, Contents, Services	98.31%	98.31%	98.31%	98.31%	98.31%	98.31%	98.31%
Local production for local consumption - Hardware (US\$ billion)	\$0.13	\$0.15	\$0.16	\$0.18	\$0.19	\$0.21	\$0.23
Local production for local consumption - Software, Contents, Services (US\$ billion)	\$0.54	\$0.60	\$0.65	\$0.72	\$0.79	\$0.86	\$0.92
Total Local production for local consumption	\$0.68	\$0.74	\$0.81	\$0.89	\$0.98	\$1.08	\$1.15
Local Producer Surplus - Hardware (US\$ billion)	\$0.06	\$0.07	\$0.07	\$0.08	\$0.09	\$0.09	\$0.10
Local Producer Surplus - Software, Contents, Services (US\$ billion)	\$0.42	\$0.46	\$0.51	\$0.56	\$0.61	\$0.67	\$0.71
Total Producer Surplus (\$ billion)	\$0.48	\$0.53	\$0.58	\$0.63	\$0.70	\$0.76	\$0.82

Sources: Statista Market Insights; Telecom Advisory Services analysis

By relying on a ratio estimated for 5 GHz and 6 GHz, AR/VR related products based on the estimations of indirect impact made above, we were able to isolate the specific economic contribution of the 6 GHz band. Following a similar procedure as that described above for IoT, the direct contribution from the AR/VR ecosystem in India attributed to 2.4 GHz and 5 GHz bands is estimated at US\$ 148 million in 2024 (see Table 3-51).

Table 3-51. India: AR/VR ecosystem direct contribution due to 2.4 GHz and 5 GHz bands (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Producer Surplus (\$ billion)	\$0.48	\$0.53	\$0.58	\$0.63	\$0.70	\$0.76	\$0.82
Share Due to Wi-Fi 6 or less (includes a discount for Wi-Fi usage)	30.88%	29.32%	27.76%	26.21%	24.61%	22.97%	21.28%
Producer surplus attributable to Wi-Fi 6 or less (US\$ million)	\$148	\$154	\$161	\$166	\$171	\$176	\$174

Sources: Statista Market Insights; Telecom Advisory Services analysis

Following the previous analysis, we were able to estimate which portion of AR/VR producer surplus growth that can be attributed to the 6 GHz band. As Table 3-52 indicates, we expect the additional AR/VR surplus generated by the 6 GHz band to account for US\$ 171 million in 2024.

Table 3-52. India: AR/VR ecosystem direct contribution due to the 6 GHz band (2024-2030)

Variable	2024	2025	2026	2027	2028	2029	2030
Total Producer Surplus (US\$ billion)	\$0.48	\$0.53	\$0.58	\$0.63	\$0.70	\$0.76	\$0.82
Attributable Wi-Fi to the 6 GHz band	35.72%	37.27%	38.83%	40.39%	41.99%	43.63%	45.31%
Attributable to Wi-Fi	66.60%	66.60%	66.60%	66.60%	66.60%	66.60%	66.60%
Impact of Wi-Fi 6E	\$171	\$196	\$225	\$256	\$292	\$333	\$370

Sources: Statista Market Insights; Telecom Advisory Services analysis

* * * * *

Wi-Fi will also generate economic value equivalent to the producer surplus of Indian firms that are part of the Wi-Fi ecosystem:

- The producer surplus of residential Wi-Fi devices and equipment manufactured in India across Wi-Fi standards amounts to US\$ 296 million in 2024 and US\$ 1.1 billion in 2034.
- The producer surplus of local firms providing products and services in the IoT ecosystem (connectivity, apps, platforms, and related professional services) in India amounts to US\$ 4.2 billion in 2024 and forecast to reach US\$ 762 million in 2034.
- The total producer surplus of local firms providing products and services in the AR/VR ecosystem (hardware, software and content) across Wi-Fi standards in India is estimated at US\$ 217 million in 2024 and US\$ 269 million in 2027.

3.6. Total economic value of allocating the full 6 GHz band for Wi-Fi

The cumulative economic value between 2024 and 2034 for the first alternative (baseline scenario plus allocating the full 6 GHz band for unlicensed use) amounts to US\$ 4,030 billion, comprising US\$ 3,544 billion in GDP contribution, US\$ 158 billion in producer surplus and US\$ 329 billion in consumer surplus (see table 3-53).

Table 3-53. India: Economic value of Wi-Fi in case of full allocation of 6 GHz band for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
2. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 329,353
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7	\$ 2,828		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 19,141		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,824		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 159,698
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 16,565	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 993,114
	3.4. Benefits derived from reduced latency			\$ 1,277,606
	3.5. Enhanced IoT deployment			\$ 772,904
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 9,007
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 7,911	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 809
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,128
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,707	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,652	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 115,933	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 5,480	
TOTAL (in US\$ billion)		\$ 328.7	\$ 157.7	\$ 3,543.6

Source: Telecom Advisory Services analysis

4. ECONOMIC VALUE OF ALLOCATING 500 MHZ FOR UNLICENSED USE AND 700 MHZ FOR IMT

The second allocation alternative of the 6 GHz band to be evaluated consists of splitting the band between Wi-Fi and IMT, allocating the lower 500 MHz for Wi-Fi, and the upper 700 MHz band for use by telecommunication service providers. In comparison with the first alternative assessed in chapter 4, this option values (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline”, which is exactly the same as the one assessed in chapter 3), and (ii) the value of allocating only 500 MHz of the 6 GHz band for Wi-Fi use. In addition, to allow for an “apples to apples” comparison, this option includes an assessment of the value to be captured through an auction of the upper part of the 6 GHz band to be used in 5G and 6G.

This chapter begins by estimating the technical implications of allocating only 500 MHz rather than 1200 MHz to Wi-Fi. On this basis, it presents its economic implications. The final section presents the estimation of proceeds to be generated by a potential auction of the 700 MHz to be allocated to IMT.

4.1. Technical implications of allocating 500 MHz in the 6 GHz band

Our overarching objective is to assess Wi-Fi performance, operating under two scenarios (1200 MHz and 500 MHz of the 6 GHz band), in terms of the **number of potential devices to be served simultaneously and the speed and latency received by each device**. The impact on speed, latency and number of devices are critical inputs in estimating Wi-Fi economic contribution. The estimation of number of devices, speed and latency is based on the following parameters:

- The **number of channels** available in different frequency bands defines the total bandwidth available in a frequency band.
- **Bandwidth allocated by channel** determines the number of devices to be supported by each standard and frequency band.
- The **spatial streams** available by device: Wi-Fi spatial streaming is a MIMO (Multiple Input Multiple Output) transmission technique used in wireless communications to transmit or receive independent and separately coded data signals. Spatial streams allow a single device to transmit and receive at the same time simultaneously. The number of spatial streams (defined by the number of antennas) in the router and devices allows a reduction in the time required to receive the information flow.
- The **number of resource units** available by channel. A Resource Unit is a subdivision of the primary channel that allows the transmission of information required by a device, following specific Wi-Fi modulation techniques.⁴⁴ Each standard stipulates the type and number of resource units that can accommodate the maximum number of devices by channel.

⁴⁴ In technical terms, (RU) is a unit in OFDMA terminology used in 802.11ax WLAN to denote a group of 78.125 kHz bandwidth subcarriers (tones) used in both DownLink (DL) and UpLink (UL) transmissions. With OFDMA, different transmit powers may be applied to different Resource Units.

- The **modulation technique** allows compressing information to allow the transmission of packets in bits per symbol (BPS) within a fixed time interval (TT). Wi-Fi relies on different digital modulation characteristics by standard (see table 5-1). Each modulation adds bits for redundancy (Error Correction codes) that allow the recovery of information in case errors occur during the transmission.

The use of Wi-Fi 6E standard within the entire 6 GHz band can perform under several advantages (see table 4-1).

Table 4-1. Wi-Fi 6E under a full 6 GHz band

Total available bandwidth (MHz)		1760
Possible channelization		20MHz, 40 MHz, 80MHz, 160MHz
Maximum number of channels	20 MHz	88
	40 MHz	43
	80 MHz	21
	160 MHz	9
	320 MHz	
Maximum allowed modulation (QAM)		1024
Maximum speed (Mbps) 1SS		1,200.98
Maximum medium access		OFDMA
Type of transmission		MU-MIMO
Maximum spatial streams (SS)		8
Maximum speed (Mbps) under maximum spatial streams		9,607.84
Improvement relative to Wi-Fi 6		Increase of bandwidth to accommodate a larger number of users with similar speeds as the prior standard; in addition, channel aggregation allows increasing the speed in a dynamic fashion according to device requirements

Source: Telecom Advisory Services compilation

A restriction in the amount of spectrum available for Wi-Fi introduces a limitation in the band performance and consequently in its economic value (see detailed analysis by effect in Appendix C). An analysis was conducted for each source of economic value as presented in chapter 2 and assessed for a full band allocation in chapter 3 (see table 4-2).

Table 4-2. Impact of 500 MHz limitation on economic impact of the 6 GHz band

Sources	Effects	Reduction of economic impact from 1200 MHz	Key limitation drivers
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	No reduction effect assumed	
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population	41.18 %	• Speed of access to content • Number of simultaneous users • Available bandwidth
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under 6 GHz	41.18 %	• Available bandwidth
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	N/A	
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	No reduction effect assumed	
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	N/A	
	2.2. Avoidance of inside wiring investment	N/A	
	2.3. Consumer benefit derived from faster broadband speed	Speed for connections above 150 Mbps is capped at 600 Mbps	• Available bandwidth • Number of Resource Units available
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	Sales reduction from 3.04% in 2028 to 15.52% in 2034, according to speed cap	• Speed maximum of connections • Number of devices using 6 GHz band for residential use
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas	40.48 %	• Number of 20 MHz channels
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi	Savings adjusted in same proportion as speed	• Internet traffic by WiFi • Speed maximum of connections
	3.2. Avoidance of enterprise building inside wiring	N/A	
	3.3. Benefits derived from an increase in average speed	Speed for connections above 150 Mbps is capped at 600 Mbps	• Available bandwidth • Number of Resource Units available
	3.4. Benefits derived from reduced latency	Latency improvements adjusted in the same proportions as speed	• Available bandwidth • Connection speed
	3.5. Enhanced IoT deployment	58.33 %	• Available bandwidth
	3.6. Deployment of Augmented Reality/Virtual Reality solutions	81.82 %	• Available bandwidth • Less users
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi	83.33 %	• Number of 320 MHz available channels • Connection speed
	4.2. Revenues of Wi-Fi based Public Internet Service Providers	66.67 %	• Available 320 MHz channels • Number of Resource Units available
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers	40.48%	• Number of 20 MHz channels
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use	Sales reduction from 3.04% in 2028 to	• Speed maximum of connections • Number of devices using 6 GHz band for residential use

		15.52% in 2034, according to speed cap	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment	Sales reduction from 3.04% in 2028 to 15.52% in 2034, according to speed cap	• Speed maximum of connections • Number of devices using 6 GHz band for industrial use
	5.3. Benefits of Firms in the IoT ecosystem	58.33 %	• Available bandwidth
	5.4. Benefits of firms in the AR/VR ecosystem	81.82 %	• Available bandwidth • Less users

The reduction from the 1200 MHz alternative was factored in the assessment of WI-FI economic value of the 500 MHz alternative.

4.2. Economic implications for Wi-Fi of allocating 500 MHz in the 6 GHz band

The cumulative economic value of Wi-Fi by allocating only the lower 500 MHz of the 6 GHz band for WI-FI devices is composed of two areas: (i) the value generated by WI-FI in the 2.4 GHz and 5 GHz bands (the “baseline” value); and (ii) the additional value derived by relying on 500 MHz in the 6 GHz band. Both areas have been estimated for the 2024-2034 period.

The “baseline” economic value amounts to US\$ 924 billion and is composed of US\$ 600 billion in GDP contribution, US\$ 299 billion in consumer surplus, and US\$ 26 billion in producer surplus (see table 4-3).

Table 4-3. India: Economic value of Wi-Fi in the baseline scenario (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
2. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 383		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 186,728
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E	\$ 0		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 0		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 0		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 11,883		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 106,244
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 10,962	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 0
	3.4. Benefits derived from reduced latency			\$ 230,990
	3.5. Enhanced IoT deployment			\$ 71,208
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 2,918

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 28	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 596
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 904
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 2,225	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 434	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 10,002	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 1,775	
TOTAL (in US\$ billion)		\$ 298.5	\$ 25.8	\$ 599.6

Source: Telecom Advisory Services analysis

Beyond the “baseline” value, the economic implication derived from allocating 500 MHz of the 6 GHz band amounts to US\$ 1,994 billion and is composed of US\$ 1,914 billion in GDP contribution, US\$ 23 billion in consumer surplus, and US\$ 58 billion in producer surplus (see table 4-4).

Table 4-4. India: Economic value of the 6 GHz band in case of allocating 500 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 291		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 83,892
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E	\$ 1,663		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 0		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 0		
	2.2. Avoidance of inside wiring investment	\$ 0		
	2.3. Consumer benefit derived from faster broadband speed	\$ 13,607		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 7,188		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 31,816
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 3,725	
	3.2. Avoidance of enterprise building inside wiring		\$ 0	
	3.3. Benefits derived from an increase in average speed			\$ 611,572
	3.4. Benefits derived from reduced latency			\$ 893,402
	3.5. Enhanced IoT deployment			\$ 292,397
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 201
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 1,314	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 71
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 133
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 4,057	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 3,874	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 44,141	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 674	
TOTAL (in US\$ billion)		\$ 22.8	\$ 57.8	\$ 1,913.5

Source: Telecom Advisory Services analysis

The combined value of both areas, encompassing the baseline (2.4 GHz and 5 GHz) and the 500 MHz of the 6 GHz band amounts to US\$ 2,918 billion, composed of US\$ 2,513 billion in GDP contribution, US\$ 84 billion in producer surplus and US\$ 321 billion in consumer surplus (see table 4-5).

Table 4-5. India: Total economic value of Wi-Fi in case of allocating 500 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
2. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 270,620
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E	\$ 1,663		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 13,607		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,071		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 138,060
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 14,686	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 611,572
	3.4. Benefits derived from reduced latency			\$ 1,124,392
	3.5. Enhanced IoT deployment			\$ 363,605
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 3,119
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 1,342	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 667
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,037
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,282	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,308	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 54,144	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 2,449	
TOTAL (in US\$ billion)		\$ 321.3	\$ 83.6	\$ 2,513.1

Source: Telecom Advisory Services analysis

The decrease in economic value from the first alternative of 1200 MHz allocation (US\$ 1,112 billion) is due to the following effects:

- 40.48% of Wi-Fi outdoor accessibility provided by WISPs is limited due to their restricted access in the 6GHz band.
- Wi-Fi indoor speed is restricted by 50%, which means that residential broadband access undergoes a bottleneck for lines in excess of 600 Mbps.
- Under a constant speed assumption, latency would increase under frequency allocation scenarios: in other words, the 500 MHz and 900 MHz alternatives would result in 40% less reduction of latency relative to the 1200 MHz option.
- More than half of IoT devices undergoes a limit in their indoor and outdoor access.

- 81.82% of the AR/VR devices supported in indoor environments is restricted by limits in terms of their ability to operate.

4.3. Potential auction proceeds of 700 MHz of the 6 GHz band

Part of the negative economic impact of limiting access of the 6 GHz band for Wi-Fi is mitigated by the benefits resulting from allocating 700 MHz to be auctioned for use by IMT. Economic value from this scenario amounts to US\$ 254 billion. The GSMA estimates that the allocation of mid bands to IMT in Asia and Pacific would generate a GDP contribution of US\$ 285 billion in 2030, from where US\$ 30 billion can be interpolated for India.⁴⁵ Prorating this value to the 700 MHz in the 6 GHz band yields a total GDP contribution between 2024 and 2034 of US\$ 83 billion. Additionally, by gaining access to 700 MHz, wireless service providers could generate US\$ 26 in producer surplus (primarily driven by IoT deployment) and US\$ 139 billion in consumer surplus. Finally, it is estimated that auction proceeds for 700 MHz in the 6 GHz band could generate US\$ 6 billion.

Considering the economic value associated with the 6 GHz band only, the total economic benefits between 2024 and 2034 of allocating the lower 500 MHz for unlicensed use and the upper 700 MHz band for use by IMT is US\$ 2,248 billion, of which US\$ 1,994 billion is generated by the spectrum received for unlicensed use and US\$ 254 billion would be generated by IMT.

⁴⁵ Source: GSMA, “The Socio-Economic Benefits of Mid-Band 5G Services” (February, 2022)

5. ECONOMIC VALUE OF ALLOCATING 1100 MHZ FOR UNLICENSED USE AND 100 MHZ FOR IMT

The third allocation alternative of the 6 GHz band to be evaluated consists of splitting the band between Wi-Fi and IMT, allocating 1100 MHz for Wi-Fi and the remaining 100 MHz band for use by telecommunication service providers. As in the cases of alternatives 1 and 2, this option values: (i) the contribution of unlicensed spectrum in the 2.4 and 5 GHz bands (the “baseline”, which is exactly the same as the one assessed in chapters 4 and 5), and (ii) the value of allocating 1100 MHz of the 6 GHz band for Wi-Fi use. In addition, as in alternative 2, to allow an “apples to apples” comparison, this option includes an assessment of the value to be captured through an auction of 100 MHz of the 6 GHz band to be used in 5G and 6G.

This chapter begins by estimating the technical implications of allocating 1100 MHz rather than the entire 6 GHz band to Wi-Fi. On this basis, it presents its economic implications. The final section presents the estimation of proceeds to be generated by a potential auction of the 100 MHz to be allocated to IMT.

5.1. Technical implications of allocating 1100 MHz of the 6 GHz band to Wi-Fi

Our objective in this case is to assess Wi-Fi performance, operating under the 1100 MHz scenario relative to the 1200 MHz alternative. The estimation of number of devices, speed and latency is based on the same drivers as in the 500 MHz alternative although the values differ (see table 5-1).

Table 5-1. Impact of 1100 MHz limitation on economic impact of the 6 GHz band

Sources	Effects	Reduction of economic impact from 1200 MHz	Key limitation drivers
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	No reduction effect assumed	
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population	5.88 %	• Speed of access to content • Number of simultaneous users • Available bandwidth
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under 6 GHz	5.88 %	• Available bandwidth • Speed of access to content
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	N/A	
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	No reduction effect assumed	
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	N/A	
	2.2. Avoidance of inside wiring investment	N/A	
	2.3. Consumer benefit derived from faster broadband speed	Speed for connections above 150 Mbps is capped at 1000 Mbps	• Available bandwidth • Number of Resource Units available
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	Sales reduction from according to speed cap	• Speed maximum of connections • Number of devices using 6 GHz band for residential use
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas	4.76 %	• Number of 20 MHz channels

Sources	Effects	Reduction of economic impact from 1200 MHz	Key limitation drivers
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi	Savings adjusted in same proportion as speed	• Internet traffic by WiFi • Speed maximum of connections
	3.2. Avoidance of enterprise building inside wiring	N/A	
	3.3. Benefits derived from an increase in average speed	Speed for connections above 150 Mbps is capped at 1000 Mbps	• Available bandwidth • Number of Resource Units available
	3.4. Benefits derived from reduced latency	Latency improvements adjusted in the same proportions as speed	• Available bandwidth • Connection speed
	3.5. Enhanced IoT deployment	8.33 %	• Available bandwidth
	3.6. Deployment of Augmented Reality/Virtual Reality solutions	60 %	• Available bandwidth • Less users
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi	12.96 %	• Number of 320 MHz available channels • Connection speed
	4.2. Revenues of Wi-Fi based Public Internet Service Providers	No reduction effect assumed	• Available 320 MHz channels • Number of Resource Units available
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers	4.76 %	• Number of 20 MHz channels
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use	Sales reduction according to speed cap	• Speed maximum of connections • Number of devices using 6 GHz band for residential use
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment	Sales reduction according to speed cap	• Speed maximum of connections • Number of devices using 6 GHz band for industrial use
	5.3. Benefits of Firms in the IoT ecosystem	8.33 %	• Available bandwidth
	5.4. Benefits of firms in the AR/VR ecosystem	60 %	• Available bandwidth • Less users

5.2. Economic implications for WI-FI of allocating 1100 MHz to the 6 GHz band

The cumulative economic value of allocating 1100 MHz of the 6 GHz band for Wi-Fi is composed of two areas: (i) the value generated by Wi-Fi in the 2.4 GHz and 5 GHz bands (the “baseline” value); and (ii) the additional value derived by relying on 1100 MHz in the 6 GHz band. Both areas have been estimated for the 2024-2034 period.

The “baseline” economic value is the same as in the prior alternatives and is, consequently skipped for brevity. On the other hand, the value derived from allocating 1100 MHz of the 6 GHz band amounts to US\$ 3,019 billion and is composed of US\$ 2,870 billion in GDP contribution, US\$ 30 billion in consumer surplus, and US\$ 120 billion in producer surplus (see table 5-2).

Table 5-2. India: Economic value of the 6 GHz band in case of allocating 1100 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 291		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 134,239
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E	\$ 2,661		
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions	\$ 0		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 0		
	2.2. Avoidance of inside wiring investment	\$ 0		
	2.3. Consumer benefit derived from faster broadband speed	\$ 19,141		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 7,941		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 50,910
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 5,603	
	3.2. Avoidance of enterprise building inside wiring		\$ 0	
	3.3. Benefits derived from an increase in average speed			\$ 993,114
	3.4. Benefits derived from reduced latency			\$ 1,046,616
	3.5. Enhanced IoT deployment			\$ 643,244
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 974
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 6,861	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 213
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 213
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 4,482	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,218	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 97,107	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 1,482	
TOTAL (in US\$ billion)		\$ 30.1	\$ 119.8	\$ 2,869.5

Source: Telecom Advisory Services analysis

The combined value of both areas, encompassing the baseline (2.4 GHz and 5 GHz) and the 1100 MHz of the 6 GHz band amounts to US\$ 3,943 billion, composed of US\$ 3,469 billion in GDP contribution, US\$ 146 billion in producer surplus and US\$ 329 billion in consumer surplus (see table 5-3).

Table 5-3. India: Total economic value of Wi-Fi in case of allocating 1100 MHz for Wi-Fi (2024-2034) (in US\$ millions)

Source	Effects	Consumer Benefit	Producer surplus	GDP contribution
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites	\$ 674		
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			\$ 320,967
	1.3. Surplus to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E	\$ 2,661		
	1.4. Surplus to consumers relying on Wi-Fi in educational institutions	\$ 215,592		
	1.5. Use of Wi-Fi in highly dense heterogeneous environments	\$ 49		
2. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port	\$ 63,768		
	2.2. Avoidance of inside wiring investment	\$ 6,833		
	2.3. Consumer benefit derived from faster broadband speed	\$ 19,141		
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment	\$ 19,824		
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			\$ 157,154
3. Enterprise Wi-Fi	3.1. Savings in business Internet traffic transmitted through Wi-Fi		\$ 16,565	
	3.2. Avoidance of enterprise building inside wiring		\$ 421	
	3.3. Benefits derived from an increase in average speed			\$ 993,114
	3.4. Benefits derived from reduced latency			\$ 1,277,606
	3.5. Enhanced IoT deployment			\$ 714,453
	3.6. Deployment of Augmented Reality/Virtual Reality solutions			\$ 3,892
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi		\$ 6,889	
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			\$ 809
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			\$ 1,117
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use		\$ 6,707	
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment		\$ 4,652	
	5.3. Benefits of Firms in the IoT ecosystem		\$ 107,109	
	5.4. Benefits of firms in the AR/VR ecosystem		\$ 3,257	
TOTAL (in US\$ billion)		\$ 328.5	\$ 145.6	\$ 3,469.1

Source: Telecom Advisory Services analysis

In this case, there is also a decrease in economic value with respect to the first alternative (US\$ 87 billion) driven by:

- Nearly 5% of Wi-Fi outdoor accessibility provided by WISPs is limited due to their restricted access in the 6GHz band.
- Wi-Fi indoor capability is restricted to only 1100 MHz, which means that residential broadband access undergoes a bottleneck for lines in excess of 1000 Mbps.
- 8.33% of IoT devices undergoes a limit in their indoor and outdoor access.
- More than 5% of total users of free hot spots are affected in Internet access due to the restriction of the upper part of the 6 GHz band for outdoor use.
- 60% of the traffic of AR/VR devices for outdoor and indoor environments undergoes limits in terms of their ability to interoperate within AR/VR ecosystems.

5.3. Potential auction proceeds of 100 MHz of the 6 GHz band

As expected, the allocation of 100 MHz for IMT will mitigate a part of the value reduction in comparison with the first alternative (US\$ 41 billion):

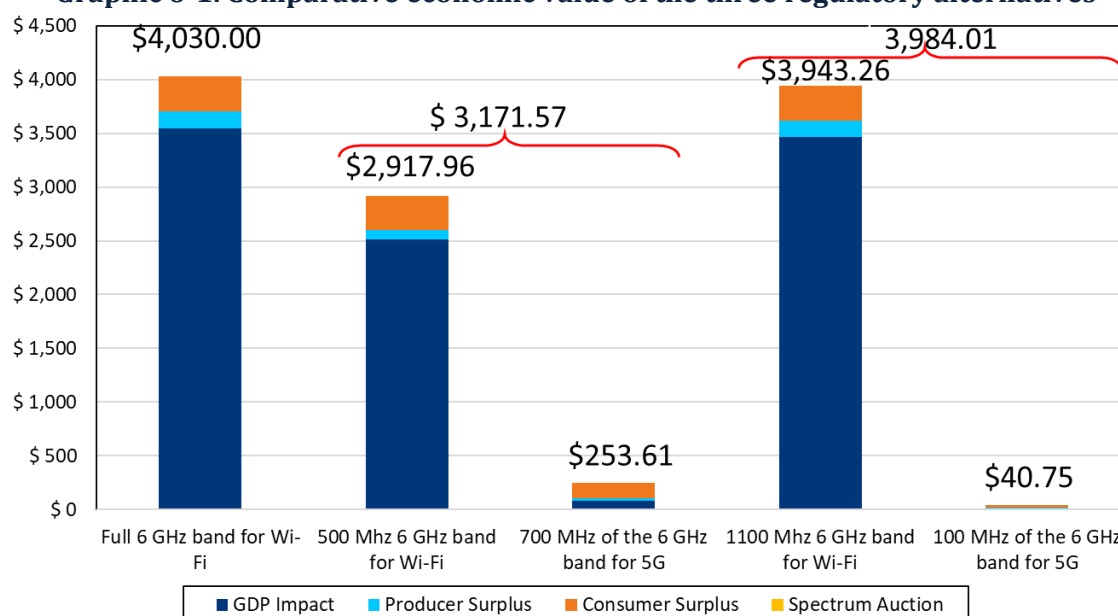
- Prorating the GDP contribution estimated by GSMA to the case of 100 MHz in the 6 GHz band yields a total GDP contribution between 2024 and 2034 of US\$ 12 billion.
- Additionally, by gaining access to 100 MHz, wireless service providers could generate US\$ 4 billion in producer surplus (primarily driven by IoT deployment) and US\$ 24 billion in consumer surplus.
- Finally, it is estimated that auction proceeds for 100 MHz in the 6 GHz band could generate US\$ 1 billion.

Considering the economic value associated with the 6 GHz band only, the total economic benefits between 2024 and 2034 of allocating the lower 1100 MHz for unlicensed use and the upper 100 MHz band for use by IMT is US\$ 3,060 billion, of which US\$ 3,019 billion is generated by the spectrum received for unlicensed use and US\$ 41 billion would be generated by IMT.

6. COMPARISON OF ECONOMIC VALUE OF ALL THREE ALTERNATIVES AND POLICY IMPLICATIONS

A comparison of the three regulatory alternatives indicates that the highest economic impact is associated with the full allocation of the 6 GHz band for use by Wi-Fi (see Graphic 6-1).

Graphic 6-1. Comparative economic value of the three regulatory alternatives



Source: Telecom Advisory Services analysis

As indicated in graphic 6-1, the full allocation to Wi-Fi is US\$ 46 billion higher than the third alternative estimated, and US\$ 858 billion than the second one. These advantages occur, even considering revenues collected from spectrum auctions, and without contemplating the costs to IMT generated by spectrum refarming. In summary, the allocation of the 1200 MHz of the 6 GHz will generate the highest economic value for India, which becomes the most attractive alternative of the three under consideration.

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APPENDIX A. Methodology for calculating the impact of speed on consumer benefit

According to Quotient Associates (Wi-Fi Alliance, 2017), Wi-Fi 4 (802.11n) and Wi-Fi 5 (802.11ac) standards rely on 2.4 GHz and 5 GHz spectrum bands. Typical channel deployment and theoretical maximum speeds within those standards indicate that 80% of the traffic is generated by devices operating in the 2.4 GHz band⁴⁶ (See Table A-1).

Table A-1. Relationship between speed and bandwidth in the most widely used Wi-Fi standards

Spatial streams	Technology	Band	Typical piping			
			20MHz	40MHz	80MHz	160MHz
1x1	802.11n	2.4 and 5 GHz	72 Mbps	150 Mbps		
	802.11ac	5 GHz	87 Mbps	200 Mbps	433 Mbps	867 Mbps

Source: Adapted from Wi-Fi Alliance (2017).⁴⁷

As indicated in table A-1, the 802.11n standard with a typical 20 MHz configuration results in an average device speed of 72 Mbps. Additionally, real-world factors such as network congestion, signal interference, and device capabilities mean that the actual speeds experienced by users are often lower, thereby affecting the overall performance and reliability of Wi-Fi connections. For example, a household with 26 devices, equipped with a router operating in Wi-Fi 6 in the frequencies of 2.4 GHz and 5 GHz can accommodate 28 channels of 20 MHz, under the largest number of resource units by channel (242 RU), can handle a maximum of 28 of 1 spatial stream users, with a maximum speed of 103.79 Mbps.

Considering that mobile broadband speeds are 208 Mbps (see table 4-1 above), we assume an impact of zero consumer benefit. It is, therefore, implied that the **consumer benefit derived from Wi-Fi speed materializes only under Wi-Fi 6E operating on the 6 GHz band.**

A.1. Consumer benefit derived from Wi-Fi speed increase under Wi-Fi 6E, and Wi-Fi 7 operating in the 6 GHz and in the 7 GHz bands

As mentioned above, Wi-Fi speed to be delivered within the household is a function of the amount of bandwidth assigned by frequency bands (consequently the number of enabled channels), the Wi-Fi standard, and the number of devices to be interconnected.

If a household is equipped with 21 devices and migrates to a Wi-Fi 6E router relying on the 6 GHz band, the assumptions to determine the theoretical maximum speed are four: (i) the maximum channelization of 80 MHz, (ii) the maximum number of resource units would be 980 (RU) in that bandwidth, (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8 μs and its guard interval in 0.8 μs. Thus, applying equation 1, the maximum speed reached in this scenario can be 1200.98 Mbps for 2 spatial streams (SS). However, this speed is a theoretical one; in reality, the feasible speed would be 840.68 Mbps. This estimate only considers an average signal degradation rate of 30% for interference (which according to research can reach up to 50%) and does account for distance between the router and the devices.

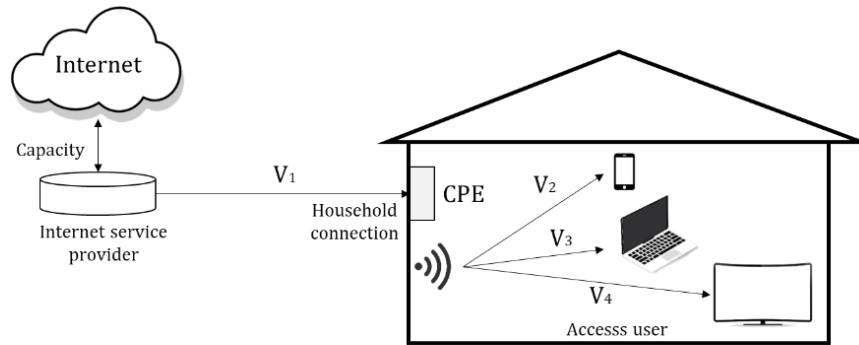
⁴⁶ Source: Gehlhaus, D et. al (2018) www.rand.org/t/RR2720

⁴⁷ Source: WiFi Alliance (2017), "Wi-Fi Spectrum Needs Study." Table 2-1.

$$V_{max} = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10 \text{ bps} \cdot \frac{5}{6}}{13.6 \times 10^{-6} \text{ seg}} * (980) * 2 = 1,200.98 \text{ Mbps (840.68 Mbps)}$$

That being said, the speed delivered at the device level is not only dependent on Wi-Fi's capability. In addition to Wi-Fi, the fixed broadband plan contracted with the Internet Service Provider (ISP) is also a key determinant. In general terms, the access speed within the home can never be higher than the effective speed of the connection (see Figure A-1).

Figure A-1. Relationship between connection speed and user access



Where: $V_1 > V_2, V_3$

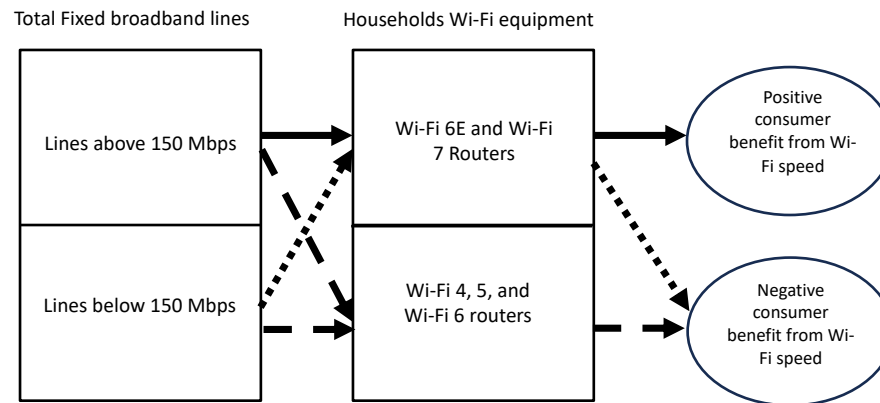
Source: Telecom Advisory Services.

Access to the fixed broadband connection through Wi-Fi technology determines the maximum speed that can be accessed by a user device. Going back to the examples presented above, if the household acquires a broadband plan of 30 Mbps but is equipped with a Wi-Fi router operating with Wi-Fi 6E standard, the speed delivered at the device level cannot exceed 30 Mbps. Conversely, if the household acquires a service plan of 1 Gbps but is equipped with a Wi-Fi 6 router operating in the 2.4 GHz and 5 GHz frequencies, the speeds delivered at the device level will be constrained by the router's capability. The reliance on the two frequencies represents an implicit threshold in speed capability. For example, if the household has 26 devices, the assumptions to determine the theoretical maximum speed at the device level with a Wi-Fi 6 router operating in 2.4 GHz and 5 GHz bands are four: (i) the minimum channelization is 20 MHz, (ii) the maximum number of resource units would be 242 (RU) in each channel, (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8μs and its guard interval 0.8μs. Thus, the maximum theoretical speed reached in this scenario can be 148.28 Mbps for 1 spatial stream (SS), which has to be discounted by 30% due to signal degradation, thus reaching:

$$V_{max} = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10 \text{ bps} \cdot \frac{5}{6}}{13.6 \times 10^{-6} \text{ seg}} * (242) * 1 = 148.28 \text{ Mbps (103.20 Mbps)}$$

On this basis, the estimation of consumer benefit derived from Wi-Fi speed under Wi-Fi 6E, operating in the 6 GHz band needs to exclude all fixed broadband lines in household equipped with a Wi-Fi router under the Wi-Fi threshold. We define such threshold to be 150 Mbps (which is conservative given the speed limits demonstrated above).

Figure 4-2. Wi-Fi Residential Benefit Conditions

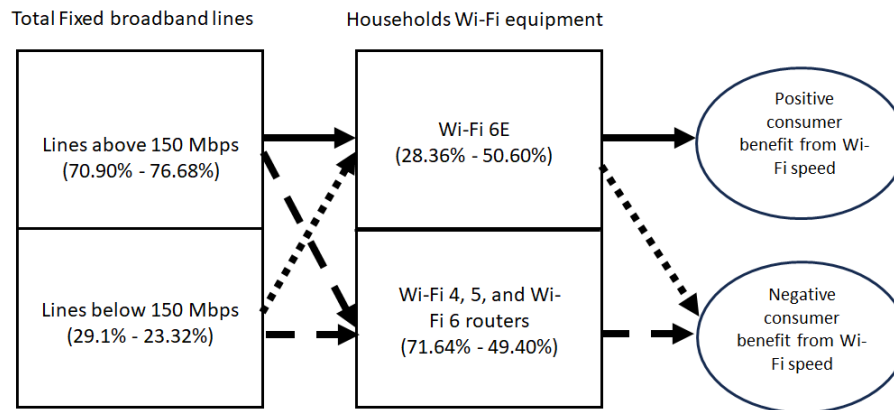


Note: Broadband households can also address connectivity needs through wired Ethernet (see section 4.3)
Source: Telecom Advisory Services.

How do we reconcile the 150 Mbps threshold at the router level with the average download speed reported by Ookla at the time with practically no Wi-Fi 6E deployment (174 Mbps in 2020 and 211 Mbps in 2021)? Two factors are at play: (i) a portion of residences rely on Ethernet wiring, and consequently do not encounter a Wi-Fi bottleneck, (ii) overall speed is a function of channels and resource units, which can be driven by the number of devices. Following on the example cited above, if the residence has a significantly smaller number of devices than 26, speeds will necessarily improve.

In other words, household residences benefit from Wi-Fi 6E additional speeds if the fixed line acquired is higher than 150 Mbps. As described above, the households acquiring a 150 Mbps (or faster) fixed broadband line will be affected due to router bottlenecks in the counterfactual scenario with no Wi-Fi 6E. Based on the percentage of graphic 4-2, we can provide a first estimate of households that benefit from Wi-Fi 6E (see figure 4-3).

Figure A-2. Wi-Fi Residential Benefit Conditions (2023-24)



Source: Telecom Advisory Services.

The first step in the analysis is to account for the households affected, specifically those purchasing a download speed of more than 150 Mbps (70.9% of households in 2023 to 87.9% of households in

). It is crucial to consider that not all the traffic from these households goes through Wi-Fi networks. Thus, the percentage of traffic that uses Wi-Fi must be deducted. Taking these two factors into account, we determine the percentage of traffic affected. For instance, in 2023, 70.90% of households had connections over 150 Mbps, but only 53.86% of their traffic went through Wi-Fi, resulting in a 38.19% share of traffic affected.

In terms of speeds, it is noted that the purchased speeds (within the subgroup of over 150 Mbps) are increasing over time (in average from 721 Mbps in 2023 to 1,245 Mbps in 2027). However, these Wi-Fi 6E speeds are capped at 1,186 Mbps due to the router bottleneck. Since previous average speeds include speeds above 1,186 Mbps, we must recalculate the average considering this cap, resulting in average speeds ranging from 721 Mbps in 2023 to 869 Mbps in 2027. Considering both factors, we arrive at the speeds with Wi-Fi 6E in comparison to the world without Wi-Fi 6E (using the mobile broadband download speed). By comparing these speeds and using the Nevo curve, we can estimate the willingness to pay for both speeds, thereby deriving the additional consumer benefit.

APPENDIX B. TECHNICAL ANALYSIS OF PERFORMANCE OF UNLICENSED SPECTRUM

The assessment of economic value of unlicensed spectrum is contingent upon a technical analysis of performance under different scenarios combining the standards and alternate frequency band allocations – i.e. 2.4 GHz and 5 GHz for Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6, and 6 GHz for Wi-Fi 6E. This document explains the assumptions, methodology and calculations used to estimate the economic impact according to technical performance of each scenario. It has been conducted for three scenarios:

- Wi-Fi 4, Wi-Fi 5, Wi-Fi 6 and Wi-Fi 6E relying on the 2.4 GHz and 5 GHz bands: under this scenario, beyond the legacy standards the Wi-Fi 6E standard operating in 2.4 GHz and 5 GHz bands already represents an improvement in signal modulation vis-a-vis Wi-Fi 6 when operating in the same bands.
- Wi-Fi 6E operating in the 1200 MHz of the 6 GHz band, which by allowing the aggregation in channels of 160 MHz, represents a significant performance improvement. This feature allows doubling the maximum channel bandwidth and improving the maximum speed.
- Wi-Fi 6E operating in the 1100 MHz of the 6 GHz band

This Appendix is structured in three sections. Section B.1 presents the variables and equations used to estimate Wi-Fi performance under different bands and standards. Section B.2 presents calculations to support the performance of Wi-Fi standards operating in the 2.4, and 5 GHz bands. Section B.3 presents the calculations supporting the added benefit in performance when using Wi-Fi 6E operating in the 6 GHz bands.

B.1. Theoretical framework for assessing Wi-Fi performance

Each Wi-Fi standard can be used in different spectrum bands. The operations of Wi-Fi4 (802.11n), Wi-Fi5 (802.11ac) and Wi-Fi 6 (802.11ax) rely on the 2.4 GHz and 5 GHz bands. Wi-Fi 6E (802.11ax) operates within the 2.4 GHz, 5 GHz and 6 GHz bands. Our overarching objective is to assess Wi-Fi performance, operating under different frequency band allocations and standard scenarios, in terms of the **number of potential devices to be served simultaneously and the speed and latency received by each device**. The impact on speed, latency and number of devices are critical inputs in estimating Wi-Fi economic contribution. The estimation of number of devices, speed and latency is based on the following parameters:

- The **number of channels** available in different frequency bands defines the total bandwidth available in a frequency band, following the Unlicensed National Information Infrastructure (UNII) scheme.
- The **bandwidth allocated by channel** determines the number of devices to be supported by each standard.
- The **spatial streams** available by device determine Wi-Fi spatial streaming is a MIMO (Multiple Input Multiple Output) transmission technique used in wireless communications to transmit or receive independent and separately coded data signals. Spatial streams allow a single device to transmit and receive at the same time

simultaneously. The number of spatial streams (defined by the number of antennas) in the router and receiving device allows a reduction in the time required to receive the information flow.

- The **number of resource units** available by channel. A Resource Unit is a subdivision of the primary channel that allows the transmission of information required by a device, following specific Wi-Fi modulation techniques.⁴⁸ Each standard stipulates the type and number of resource units that can accommodate the maximum number of devices by channel.
- The **modulation technique** allows compressing information to allow the transmission of packets in **bits per symbol** (BPS) within a **fixed time interval** (TT). Modulation techniques are roughly divided into four types: Analog modulation, Digital modulation, Pulse modulation, and Spread spectrum method. Wi-Fi relies on different digital modulation characteristics by standard (see table B-1). Each modulation adds bits for redundancy (Error Correction codes) that allow the recovery of information in case errors occur during the transmission.

Table B-1. Wi-Fi standards transmission characteristics

Standard	Modulation	Bits per symbol (BPS)	Error correction (EC)	Transmission time (TT)
Wi-Fi5	256 QAM	8	5/6	3.6 us
Wi-Fi 6	1024 QAM	10	5/6	13.6 us
Wi-Fi 6E	1024 QAM	10	5/6	13.6 us

Source: IEEE Computer Society, (2021). "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications" <https://ieeexplore.ieee.org/document/9442429>

The speed delivered by a particular Wi-Fi standard is calculated as follows:

$$\text{Speed} = \frac{\text{Bits per symbol} \cdot \text{Error Correction}}{\text{Transmission Time}} * \text{Resource Units} * \text{Spatial Steams} \quad (\text{Eq. 1})$$

Source: National Instruments. "Introduction to Wireless LAN Measurements from 802.11a to 802.11ac" Reference to IEEE. (2016), "Performance comparison of IEEE 802.11n and IEEE 802.11ac" https://download.ni.com/evaluation/rf/Introduction_to_WLAN_Testing.pdf

Having specified the equation to calculate the number of devices and speed we can estimate the performance of Wi-Fi under different frequency bands and standards.

B.2. Wi-Fi 6 performance operating under 2.4 and 5 GHz bands

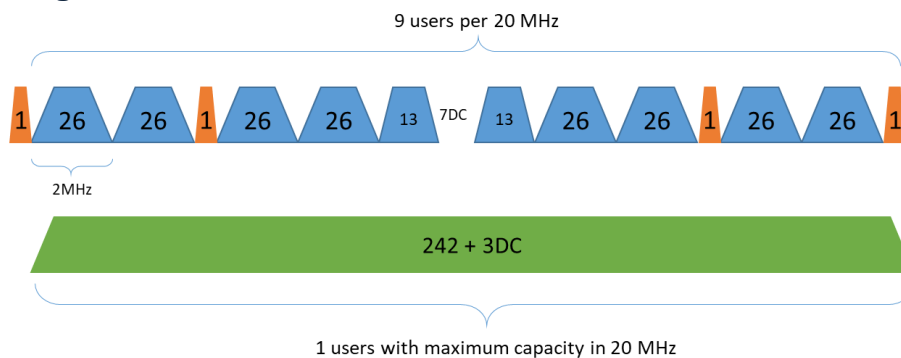
Taking into consideration that the Wi-Fi4 and 5 standards have been presenting challenges in terms of saturation due to the large amount of equipment and devices deployed, as well as the restriction of the maximum available bandwidth, 802.11ax technology, known as Wi-Fi 6, offered a solution. The main features of Wi-Fi 6 can be summarized in five areas according to

⁴⁸ In technical terms, (RU) is a unit in OFDMA terminology used in 802.11ax WLAN to denote a group of 78.125 kHz bandwidth subcarriers (tones) used in both DownLink (DL) and UpLink (UL) transmissions. With OFDMA, different transmit powers may be applied to different Resource Units.

the following reference⁴⁹: (i) increased channel aggregation⁵⁰ due to increased bandwidth at the 6 GHz frequency, (ii) channel splitting by multiple access of multiple users by orthogonal frequency division⁵¹ (OFDMA), (iii) transmission link adaptation through maximum 1024-QAM modulation⁵², (iv) guard or guard interval to avoid information overlap⁵³; and, (v) transmission of multiple simultaneous information streams over the same channel to increase bandwidth⁵⁴.

In this context, if we consider a saturation scenario for a single user per channel, occupying 802.11ax technology (Wi-Fi 6), the assumptions to determine the theoretical maximum speed would be four: (i) the technology could be executed from a minimum channelization of 20 MHz (both in the 2.4 GHz or 5 GHz band), (ii) the maximum number of subchannels occupied by such user would be 242 resource units (RU) in such bandwidth (see Figure B-1), (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8µs and its guard interval 0.8µs.

Figure B-1. Channelization for Wi-Fi 6 in a 20 MHz wide channel



Source: Telecom Advisory Services adapted from CISCO⁵⁵

Table B-2 presents all parameters driving Wi-Fi 6 performance under 2.4 GHz and 5 GHz bands.

⁴⁹ IEEE Computer Society, (2021). “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications” <https://ieeexplore.ieee.org/document/9442429>

⁵⁰ The maximum bandwidth for Wi-Fi 6 operation in the 2.4 GHz band corresponds to 3 channels of 20 MHz or 1 channel of 40 MHz in the 5 GHz band, it corresponds to 25 channels of 20 MHz, 6 channels of 80 MHz or 2 channels of 160 MHz. The 6 GHz band corresponds to 59 20 MHz channels, 14 80 MHz channels or 7 160 MHz channels.

⁵¹ This allows the generation of smaller sub-channels, called Resource Units (RU), to carry information from multiple users at the same time over the entire channel. Depending on the bandwidth of the channel where the data is transmitted, up to 26 (2MHz), 52 (4MHz), 102 (8MHz), 242 (20MHz), 484 (40MHz), 980 (80MHz) or 1960 (160MHz) subchannels or RU's can be accommodated.

⁵² Wi-Fi 6 uses modulations ranging from BPSK to 1024-QAM. The difference is the number of bits per symbol that are transmitted to adapt the speed to changes in distance, antenna position and interference. Thus, BPSK can transmit up to 1 bit per symbol, whereas 1024-QAM transmits up to 10 bits per symbol. The time that each symbol lasts is defined in the protocol, and the shorter the symbol is, the more information can be sent per second, but it is easier to have errors. In 1024-QAM it is possible to have an error correction rate of 5/6, i.e. 5 bits of information and 1 bit of error correction.

⁵³ This means that there is a waiting time before sending the next symbol to make the link more robust and avoid loss of information as the data takes different paths and the information frame is assembled at the receiver. The transmission time in 1024-QAM, for example, is 12.8µs, and its guard interval corresponds to 0.8µs, i.e. a total of 13.6µs.

⁵⁴ This is achieved by the implementation of MU-MIMO technology which allows up to 8 simultaneous data streams or spatial streams to be transmitted to achieve higher transmission speeds. However, this feature also depends on the receiving equipment being able to support this technology.

⁵⁵ Source: CISCO. <https://blogs.cisco.com/networking/Wi-Fi-6-ofdma-resource-unit-ru-allocations-and-mappings>

Table B-2. Wi-Fi 6 parameters

Commercial denomination		Wi-Fi 6
IEEE standard		802.11 ax
Frequency bands		2.4 GHz, 5 GHz
ISM (Industrial Scientific and Medical band)		(B1) 2412-2472: 60MHz (ISM)
UNII (Unlicensed National Information Infrastructure)		(B2i) 5170-5330: 160MHz (UNII-1-2) (B3) 5490-5730: 240MHz (UNII-2Ex) (B4) 5735-5835: 100MHz (UNII-3)
Total available bandwidth (MHz)		560
Possible channelization		20MHz, 40 MHz, 80MHz, 160MHz
Maximum number of channels by channelization	20 MHz	28
	40 MHz	14
	80 MHz	7
	160 MHz	3
	320 MHz	
Maximum allowed modulation (QAM)		1024
Maximum speed (Mbps) 1SS		1,200.98
Maximum medium access		OFDMA
Type of transmission		MU-MIMO
Maximum spatial streams (SS)		8
Maximum speed (Mbps) under maximum spatial streams		9,607.84
Improvement relative to Wi-Fi5		Improvement technique to simultaneously transmit information at faster speed and larger bandwidth to accommodate more devices

Source: Telecom Advisory Services compilation

By relying on the parameters of table 2 and equation 1, we calculate the maximum speed for channels of 20 MHz with 242 resource units of one spatial stream (which means one user per channel). As the equation indicates, under the Wi-Fi 6 standard operating within the 2.4 and 5 GHz frequencies, we can **theoretically** accommodate 28 devices with speeds of up 148.28 Mbps.

$$Speed = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10bps \cdot \frac{5}{6}}{13.6 \mu s} * (242) * 1 = 148.28 \text{ Mbps}$$

According to this, it could be estimated that the **maximum theoretical value** that can be reached **by a user in a high traffic environment**, with a **minimum operating channel**, can be determined at **150 Mbps**. In this case, Wi-Fi 6 solves both performance and coverage challenges of Wi-Fi5. In addition, the technology introduces a combination of features including OFDMA and 1024-QAM peak modulation which improve spectral efficiency, thereby increasing speed while supporting many devices in a congested area.

In the similar way as the case above, we calculate the theoretical performance levels for different scenarios (see table B-3).

Table B-3. Performance of Wi-Fi 6 operating in the 2.4 GHz and 5 GHz bands

Scenarios	Number of channels (A)	Bandwidth by channel (B)	Spatial Streams (C)	Resource units (D)	Maximum devices per resource unit (E)	BPS	CE	TT (μs)	Total number of devices (A*E)	Channel speed (V=C*D*CE/T) (Mbps)
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1	28	20	1	26 (2MHz)	9	10	5/6	13.6	252	15.93
2	28	20	2	26 (2MHz)	9	10	5/6	13.6	252	31.86
3	28	20	1	242 (20MHz)	1	10	5/6	13.6	28	148.28
4	12	40	1	484 (20MHz)	1	10	5/6	13.6	12	296.57
5	12	40	2	484 (20MHz)	1	10	5/6	13.6	12	593.14

Source: Telecom Advisory Services analysis

This table allows estimating several theoretical scenarios of Wi-Fi performance under Wi-Fi 6:

- Scenario 1 (theoretical): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6 can handle a maximum of 252 of 1 spatial streams users, at a maximum speed of 15.93 Mbps.
- Scenario 2 (theoretical): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6 can handle a maximum of 252 of 2 spatial streams users, with a maximum speed of 31.86 Mbps.
- Scenario 3 (theoretical): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (242 RU), Wi-Fi 6 can handle a maximum of 28 of 1 spatial stream users, with a maximum speed of 148.28 Mbps.
- Scenario 4 (theoretical): this scenario allows 12 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6 can handle a maximum of 12 of 1 spatial stream users, with a maximum speed of 296.57 Mbps.
- Scenario 5 (theoretical): this scenario allows 12 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6 can handle a maximum of 12 of 2 spatial stream users, with a maximum speed of 593.14 Mbps.

It is important to consider these results to be valid only theoretically. The following factors come into play to significantly reduce the estimated speed. While the theoretical maximum speed for a user in a saturation scenario can reach 150 Mbps, this could be affected by a greater number of users making use of the channel. In fact, as described in Figure C-1, the 802.11ax standard could distribute the bandwidth to up to 9 users; and if this number increases, the user experience will be degraded due to a reduction in speed, generally in applications with high resource requirements. Considering the interference in bands allocated for indoor use, more likely feasible scenarios⁵⁶ are as follows:

⁵⁶ In this regard, it is important to consider that the performance of Wi-Fi is compromised by environmental factors such as congestion, noise and interference. The signal degradation from theoretical speed is between 9% and 49%. See Ivan Forenbacher, Siniša Husnjak, Ivan Jovović, and Mislav Bobić, Raffaele Bruno. “Throughput of an IEEE 802.11 Wireless Network in the Presence of Wireless Audio Transmission: A Laboratory Analysis”, *Sensors* DOI: 10.3390/s21082620. For purposes of this analysis, we use the midpoint of 30% of signal degradation. This value does not include the additional degradation taking place by the distance between the router and the device.

- Scenario 1 (feasible): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6 can handle a maximum of 252 of 1 spatial streams users, at a maximum speed of 11.15 Mbps.
- Scenario 2 (feasible): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6 can handle a maximum of 252 of 2 spatial streams users, with a maximum speed of 22.30 Mbps.
- Scenario 3 (feasible): this scenario allows 28 channels of 20 MHz. Under the largest number of resource units by channel (242 RU), Wi-Fi 6 can handle a maximum of 28 of 1 spatial stream users, with a maximum speed of 103.79 Mbps.
- Scenario 4 (feasible): this scenario allows 12 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6 can handle a maximum of 12 of 1 spatial stream users, with a maximum speed of 207.59 Mbps.
- Scenario 5 (feasible): this scenario allows 12 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6 can handle a maximum of 12 of 2 spatial stream users, with a maximum speed of 415.19 Mbps (again, as stipulated in footnote 8, the degradation of speed does not include the distance factor).

In sum, under the 2.4 and 5 GHz frequency bands, 12 devices in 40 MHz channels can reach a feasible maximum speed at the device level of 207.59 Mbps. This speed would increase to 415.19 Mbps if the number of spatial streams is increased from 1 to 2 for the router and all receiving devices. However, an additional problem to consider is that deployment of routers with spatial streams >1 is not totally common (note: for a spatial stream configuration to be feasible, they have to be available at the router and all receiving devices). While it is difficult to quantify the number of spatial streams existing at each device level, we have estimations at the router level. An estimated market share of spatial streams of routers is as follows: 1 and 2 streams (30%-40%), 3 and 4 (40%-50%), 5 and 8 (10%-20%, mostly in enterprise installations) (Sources: Mordor Intelligence. *Global Wi-Fi router market (2024 – 2029)*).

B.3. Wi-Fi 6E performance under the 6 GHz band and below

The key improvement of Wi-Fi 6E relative to Wi-Fi 6 is that by accessing the 6 GHz band, the number of users can be increased with a similar number of resource units. Wi-Fi 6E is used in the 2.4 GHz, 5 GHz, and 6 GHz bands according to the following performance features (see table B-4).

Table B-4. Wi-Fi 6E parameters

Commercial denomination	Wi-Fi 6E
IEEE standard	802.11 ax
Frequency bands	2.4GHz, 5 GHz y 6GHz
Industrial, Scientific and Medical (ISM) band	(B1) 2412-2472: 60MHz (ISM)
UNII (Unlicensed National Information Infrastructure)	(B2i) 5170-5330: 160MHz (UNII-1-2) (B3) 5490-5730: 240MHz (UNII-2Ex) (B4) 5735-5835: 100MHz (UNII-3) (B5) 5925-6425: 500MHz (UNII-5) (B6i) 6425-6525: 100MHz (UNII-6) (B7) 6525-6875: 350MHz (UNII-7)

		(B8i) 6875-7125: 250MHz (UNII-8)
Total available bandwidth (MHz)		1760
Possible channelization		20MHz, 40 MHz, 80MHz, 160MHz
Maximum number of channels	20 MHz	88
	40 MHz	43
	80 MHz	21
	160 MHz	9
	320 MHz	
Maximum allowed modulation (QAM)		1024
Maximum speed (Mbps) 1SS		1,200.98
Maximum medium access		OFDMA
Type of transmission		MU-MIMO
Maximum spatial streams (SS)		8
Maximum speed (Mbps) under maximum spatial streams		9,607.84
Improvement relative to Wi-Fi 6		Increase of bandwidth to accommodate a larger number of users with similar speeds as the prior standard; in addition, channel aggregation allows increasing the speed in a dynamic fashion according to device requirements

Source: Telecom Advisory Services compilation

Relying on equation 1 and based on the Wi-Fi 6E characteristics, we can estimate the maximum speed for 40 MHz bandwidth with 484 resource units (one user per channel) and 1 spatial stream.

$$Speed = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10bps \cdot \frac{5}{6}}{13.6 \mu s} * (484) * 1 = 296.57 Mbps$$

In a similar way as the case above, we calculate the theoretical performance levels for different scenarios (see table B-5).

Table B-5. Performance of Wi-Fi 6E operating in the 6 GHz band and below

Scenarios	Number of channels (A)	Bandwidth by channel (B)	Spatial Streams (C)	Resource units (D)	Maximum devices per resource unit (E)	BPS	CE	TT (μs)	Total number of devices (A*E)	Channel speed (V=C*D*CE/T) (Mbps)
1	88	20	1	26 (2MHz)	9	10	5/6	13.6	792	15.93
2	88	20	2	26 (2MHz)	9	10	5/6	13.6	792	31.86
3	88	20	1	242 (20MHz)	1	10	5/6	13.6	88	148.28
4	43	40	1	484 (40MHz)	1	10	5/6	13.6	43	296.57
5	43	40	2	484 (40MHz)	1	10	5/6	13.6	43	593.14
6	18	160	2	980	1	10	5/6	13.6	18	1,200.98

Under this case, the **feasible** performance of scenarios discounted from the theoretical case, are estimated as follows:

- Scenario 1 (feasible): this scenario allows 88 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6E can handle a maximum of 792 of 1 spatial streams users, at a maximum speed of 11.15 Mbps.
- Scenario 2 (feasible): this scenario allows 88 channels of 20 MHz. Under the largest number of resource units by channel (26 RU), Wi-Fi 6E can handle a maximum of 792 of 2 spatial streams users, with a maximum speed of 22.30 Mbps.
- Scenario 3 (feasible): this scenario allows 88 channels of 20 MHz. Under the largest number of resource units by channel (242 RU), Wi-Fi 6E can handle a maximum of 88 of 1 spatial stream users, with a maximum speed of 103.79 Mbps.
- Scenario 4 (feasible): this scenario allows 43 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6E can handle a maximum of 43 of 1 spatial stream users, with a maximum speed of 207.59 Mbps.
- Scenario 5 (feasible): this scenario allows 43 channels of 40 MHz. Under the largest number of resource units by channel (484 RU), Wi-Fi 6E can handle a maximum of 43 of 2 spatial stream users, with a maximum speed of 415.19 Mbps.

B.3.1 Latency

The demand for new high-performance, low-latency services, such as AR/VR, remote offices, cloud computing, and gaming, is increasing rapidly. These applications, which are intended for use in a variety of environments, including homes, enterprises and industrial plants, require improved performance and reliability, reduced latency (e.g., latency of less than 5 Ms for real-time gaming) and jitter, and improved energy efficiency in Wi-Fi networks. Advanced AR/VR applications require 4K-8K video, minimum throughput of 400-2350 Mbps and maximum transmission/interactivity latency on the order of 10 ms (see Table B-7).

Table B-7. Summary of latency and throughput requirements for industrial application use cases

Applications and requirements	Class A	Class B	Class C
Applications	Interactive video, real time software control, mobile robotics, automated guided vehicles (AGV)	AR/VR, remote HMI, real time cyclic control, machine control, production line control	Real-time asynchronous control, motion control, printing, packaging
Synchronization time	10-1 μ s	~1 μ s	~1 μ s
latency limit	50 -10 ms	10 - 1 ms	1ms - 250 μ s
Reliability	99% - 99.9%	99.9% - 99.99%	> 99.999%
Performance	High (Video) Low (Control, robotics, AGV)	High (VR) Moderate-Low (control, automation, AR)	Moderate-Low

Source: INTEL (2023), "Next Generation Wi-Fi: Spectrum Needs of Wi-Fi 7".

Initially, a comparison of the technical aspects on latency for Wi-Fi 6, a Wi-Fi Alliance analysis⁵⁷ refers to field tests conducted by Qualcomm Technologies in three environments: home, office and classrooms, where the response of sending information is reduced by 40%, 53% and 93%, respectively (see Table B-8).

⁵⁷ Source: Wi-Fi Alliance, "The Beacon" <https://www.Wi-Fi.org/beacon/rolf-de-vegt/reduced-latency-benefits-of-Wi-Fi-6-ofdma>

Table B-8. Latency scenarios in use cases for Wi-Fi 6 environments.

Environments	Latency (ms) Download (DL)	% DL Latency Reduction	Latency (ms) Upload (UL)	% Latency Reduction UL
Home (Normal)	15	40	76	63
Home (Wi-Fi 6)	9		28	
Office (Normal)	53	53	70	23
Office (Wi-Fi 6)	25		54	
Classroom (Normal)	452	93	5,875	99
Classroom (Wi-Fi 6)	31		66	

Source: Wi-Fi Alliance

APPENDIX C. IMPACT OF TECHNICAL ANALYSIS ON ASSESSMENT OF ECONOMIC VALUE

Based on the analyses of performance of unlicensed spectrum bands presented in Appendix B, this appendix details the implications for assessing its economic value. Each area of analysis is assessed independently following the sources of value outlined in the study methodology. The objective is to calculate the performance improvement from unlicensed spectrum operating in the 1200 MHz and 1100 MHz frequencies of the 6 GHz band and the consequent impact on the variables driving economic value (speed, latency, number of users). The effects analyzed are only the ones where the allocation of frequencies is expected to have an impact on economic value (see table C-1).

Table C-1. Sources of Wi-Fi economic value

Sources	Effects
2. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions
	1.5. Use of Wi-Fi in highly dense heterogeneous environments
3. Residential Wi-Fi	2.1. Home internet access for devices that lack an Ethernet port
	2.2. Avoidance of inside wiring investment
	2.3. Consumer benefit derived from faster broadband speed
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas
3. Enterprise Wi-Fi	3.1. Savings in business internet traffic transmitted through Wi-Fi
	3.2. Avoidance of enterprise building inside wiring
	3.3. benefits derived from an increase in average speed
	3.4. Benefits derived from reduced latency
	3.5. Enhanced IoT deployment
	3.6. Deployment of Augmented Reality/Virtual Reality solutions
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi
	4.2. Revenues of Wi-Fi based Public Internet Service Providers (WISPs)
	4.3. Revenues of Wi-Fi based Wireless Internet Service Providers
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment
	5.3. Benefits of Firms in the IoT ecosystem
	5.4. Benefits of firms in the AR/VR ecosystem

Effects where the different allocation of frequencies has an impact on economic value

C.1. Free Wi-Fi service supporting the needs of the broadband unserved population (effect 1.2)

One of the main benefits of using the 6 GHz band is the reduction of latency, and, therefore, an increase in traffic in public places, which depends on the number of connected devices that a Wi-Fi site can host simultaneously. The total number of devices (US) that a hotspot site can host depends on the allocated bandwidth (AB), the usage factor (FU), the traffic demand profile of the average user (CM) and the simultaneity factor that depends on the number of devices connected at the same time (FS). Equation 1 specifies their relationship as follows:

$$(Eq. 1) \quad US = \frac{AB}{FS \cdot \sum_{i=1}^n CM_i \cdot FU_i}$$

Where "n" represents the total number of users that are hosted in the Wi-Fi site and "i" corresponds to the individual demand profile of the users that are connected.

The following sections explain the considerations and calculations of each of the components that influence the number of users that a Wi-Fi site can handle.

Demand Profile (DC)

The demand profile represents the maximum download capacity for four types of user requirements (web pages, email, social networking, calls, video, etc.). For calculation purpose, we compile the traffic of an average Indian user: (i) web page browsing, (ii) video conferencing, (iii) music or video streaming, and (iv) calls and social networks. Traffic by service allows calculating download capacity. For example, when a user is accessing the Internet, if it is considered that a user accesses every 20 seconds one type of the most visited web content, whose average size is around 956.04 KB. Consequently, the maximum capacity assigned to the device is 382.42 Kbps (see Table C-2).

Table C-2. Size and capacity of most visited pages in India

Type	Most visited pages	Size (T) KB	Capacity (CM) Kbps
Navigation	Google	382	$CM = \frac{\bar{T}}{t} \cdot \frac{8 \text{ bits}}{1 \text{ byte}}$ $= \frac{956.04 \text{ KB}}{20 \text{ s}} \cdot \frac{8 \text{ bits}}{1 \text{ byte}} = 382.42 \text{ Kbps}$
	Youtube	171	
	Facebook	364.5	
	Instagram	3072	
	Whatsapp	2560	
	Amazon	87.4	
	Wikipedia	77.7	
	ChatGPT	79.2	
	Bing	2150.4	
	Quora	616.2	
Average size and capacity		956.04	382.42

Source: We Are Social. <https://datareportal.com/reports/digital-2024-india>

In the case of other applications such as video streaming or videoconferencing, the average maximum capacity assigned to the device is around 2,666.51 Kbps (2.60 Mbps) (Table C-3).

Table C-3. Application capacity

Applications	Capacity(CM) Kbps	Percent use
Videoconferencing (e.g., Skype)	3,000	5.2%
Video streaming (e.g., YouTube)	4,800	31.7%
Phone calls / Social networks (e.g., WhatsApp)	12.33	12.5%

Source: Webpage size: PINGDOM

By adding all usage traffic, the average capacity of a device connected to a Wi-Fi site reaches 2,095.49 Kbps (2.05 Mbps) (see Table C-4).

Table C-4. Capacity of web pages and applications
Applications and Web pages

Applications and webpages	Capacity (CM) Kbps
Internet browsing	382.42

Broadcast and Streaming (Video)	3,000
Social networks (calling)	4,800
Podcast (Videoconference)	12.33
Average total capacity	2,095.49

Source: Telecom Advisory Services analysis

Usage Factor (UF)

The usage factor corresponds to the percentage of content accessed by a single device. This value depends on the time or amount of information that the average user collects from the Internet via the Wi-Fi site. The usage factor is calculated by the daily time spent by an average user which, for the most part, is linked to Internet browsing (6h 45m - 34.6%, see Table C-5).

Table C-5. Common time spent using Internet applications in India

Internet browsing	Hours	Minutes	Total (h)	% Use
Broadcast and Streaming (Video)	4	131	6.18	31.7%
Social networks (calling)	2	26	2.43	12.5%
Podcast (Videoconference)	1	1	1.02	5.2%
Internet browsing	6	45	6.75	34.6%

Source: We Are Social; Telecom Advisory Services analysis

Simultaneity Factor

The simultaneity factor assumes that the capacity calculated above decreases by half due to the number of simultaneous users occupying a channel. In a scenario where the number of users increases by 100%, this factor is assumed to be 0.5, i.e., capacity could be reduced due to the duplication of connected devices.

Bandwidth

Considering that a Wi-Fi site uses the outdoor spectrum portions, the useful bandwidth in the 6 GHz band varies by allocation alternative (see table C-6).

Table C-6. Bandwidth scenarios

UNII	Starting frequency	Final frequency	Bandwidth (MHz)	Standard Power	Low Power	Very low Power
UNII-5	5,925	6,425	500	Outdoor/Indoor	Indoor	Indoor
UNII-6	6,425	6,525	100		Indoor	Indoor
UNII-7	6,525	6,875	350	Outdoor/Indoor	Indoor	Indoor
UNII-8	6,875	7,125	250		Indoor	Indoor

Source: DSA. Unlicensed spectrum access in the 6 GHz band

Based on the usage pattern in India and bandwidth availability the number of users and, consequently the discount factor of alternative allocation scenarios were defined (see table C-7).

Table C-7. Number of users by frequency allocation scenarios

	UNII-5 + UNII-7	UNII-5 + UNII-7
	1100MHz	1200MHz
Average capacity (from table D-4)	1854.24	1854.24
Simultaneity factor	0.5	0.5
AB (KHz)	800,000	850,000
Number of users	862.89	916.82
Reduction relative to 1200 MHz	5.88%	

Source: Telecom Advisory Services analysis

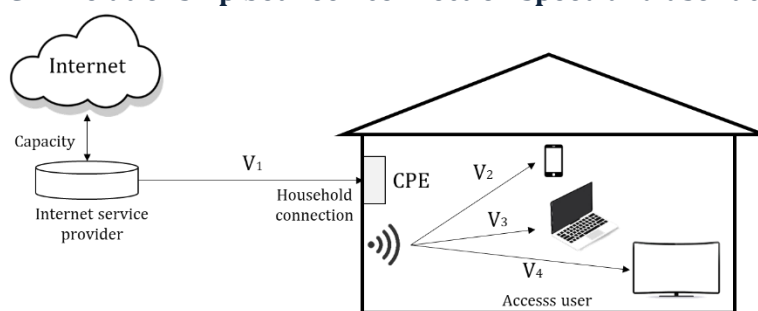
Based on this, the number of users that can be handled by a free hotspot can be estimated under frequency band allocation of 1100 MHz. While the number of users under 1200 MHz is 916.82, the reduction is estimated through the following equations 2:

$$(Eq. 2) Impact_{1100MHz} = \frac{Users_{1200} - Users_{1100}}{Users_{1200}} = \frac{916.82 - 862.89}{916.82} = 5.88\%$$

C.2. Consumer benefit derived from faster broadband speed within the residence (effect 2.3)

The network elements that play a crucial role in residential speed are the fixed broadband plan contracted with the Internet Service Provider (ISP) and the access mechanism (wired or wireless) by which a user connects⁵⁸ to the service. In general terms, the access speed within the home can never be higher than the effective speed of the connection (see Figure C-1).

Figure C-1. Relationship between connection speed and user access



Where: $V_1 > V_2, V_3, V_4$

Source: Telecom Advisory Services.

Access to the fixed broadband connection through Wi-Fi technology determines the maximum speed that can be accessed by a user device. According to Quotient Associates (Wi-Fi Alliance, 2017), Wi-Fi4 (802.11n) and Wi-Fi5 (802.11ac) standards rely on 2.4 GHz and 5 GHz spectrum bands. Typical channel deployment and theoretical maximum speeds within those standards

⁵⁸ We will call a **user** the internal customer of a household who can access the Internet through a wired or wireless medium.

indicate that 80% of the traffic is generated by devices operating in the 2.4 GHz band⁵⁹ (See Table C-8).

Table C-8. Relationship between speed and bandwidth in the most widely used Wi-Fi standards

Spatial streams	Technology	Band	Typical piping			
			20MHz	40MHz	80MHz	160MHz
1x1	802.11n	2.4 and 5 GHz	72 Mbps	150 Mbps		
	802.11ac	5 GHz	87 Mbps	200 Mbps	433 Mbps	867 Mbps

Source: Adapted from Wi-Fi Alliance (2017).⁶⁰

In this context, if the household has 26 devices, the assumptions to determine the theoretical maximum speed at the device level are four: (i) the minimum channelization is 20 MHz, (ii) the maximum number of resource units would be 242 (RU) in each channel, (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8μs and its guard interval 0.8μs. Thus, applying equation 3, the maximum theoretical speed reached in this scenario can be 148.28 Mbps for 1 spatial stream (SS), which has to be discounted by 30% due to signal degradation, thus reaching.

$$(Eq. 3) V_{max} = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10 \text{ bps} \cdot \frac{5}{6}}{13.6 \times 10^{-6} \text{ seg}} * (242) * 1 = 148.28 \text{ Mbps (103.20 Mbps)}$$

If a household has 13 devices, the assumptions to determine the theoretical maximum speed at the device level are four: (i) the minimum channelization is 40 MHz, (ii) the maximum number of resource units would be 484 (RU) in each channel, (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8μs and its guard interval 0.8μs. In this case, applying equation 1, the maximum theoretical speed reached in this scenario can be 296.57 Mbps for 1 spatial stream (SS), which has to be discounted by 30% due to signal degradation, thus reaching 207.59 Mbps.

If the household is equipped with 21 devices and migrates to a Wi-Fi 6E router relying on 1200 MHz of the 6 GHz band, the assumptions to determine the theoretical maximum speed are four: (i) the maximum channelization of 80 MHz, (ii) the maximum number of resource units would be 980 (RU) in that bandwidth, (iii) the maximum modulation would be 1024-QAM with a transmission rate (BPS) of 10 bits per symbol and error correction rate (EC) of 5/6; and, (iv) the transmission time (TT) per symbol is considered to be 12.8μs and its guard interval in 0.8μs. Thus, applying equation 5, the maximum speed reached in this scenario can be 1200.98 Mbps for 2 spatial streams (SS).

$$(Eq. 4) V_{max} = \frac{BPS \cdot CE}{TT} * RU * SS = \frac{10 \text{ bps} \cdot \frac{5}{6}}{13.6 \times 10^{-6} \text{ seg}} * (980) * 2 = 1,200.98 \text{ Mbps}$$

If the frequencies allocated for unlicensed use in the 6 GHz band are reduced from 1200 MHz, this has an impact on the number of resource units assigned for transmission, and consequently the maximum speed at the device level (see table C-9).

⁵⁹ Source: Gehlhaus, D et. al (2018) www.rand.org/t/RR2720

⁶⁰ Source: Wi-Fi Alliance (2017), "Wi-Fi Spectrum Needs Study." Wi-Fi Alliance, Table 2-1.

Table C-9. Number of resource units by frequency allocation

Allocation alternatives	Resource Units	Maximum speed ⁶¹	Percent impact from 1200 MHz
1200 MHz	1960 (7 channels of 160 MHz)	1200.98	-
1100 MHz	1706 (6 channels of 140 MHz)	1045.34	12.96%

Source: Telecom Advisory Services analysis

From these estimates, the impact of device speed under different frequency allocation scenario (1100 MHz) can be calculated:

$$(Eq. 5) \text{ Impact}_{1100\text{MHz}} = \frac{\text{Speed}_{1200} - \text{Speed}_{1100}}{\text{Speed}_{1200}} = \frac{1200.98 - 1048.34}{1200.98} = 12.96\%$$

C.3. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas (effect 2.5)

The increase in WISP connections is directly related to the growth of connections according to the allocation scenarios of the 6 GHz band.

In this regard, in order to analyze the impact of the standard upgrade on the increase of connections in homes in rural and isolated areas, two main aspects must be established: (i) the number of maximum outdoor channels influences the number of connections that could be deployed; and (ii) the number of connections for the allocation of resource units (see Table C-10).

Table C-10. Maximum number of users per 6 GHz band allocation scenarios

	1200 MHz	1100 MHz
Available bandwidth	1,200	1100
Available bandwidth outdoors (UNII-5 and UNII-7)	850	800
Number of 20 MHz channels	42	40
Maximum number users with 242 RUs	42	40
Percent impact from 1200 MHz band	0%	4.76%

Source: Telecom Advisory Services analysis

Along these lines, the impact of different frequency allocation scenarios is related to the reduction of the number of connections to be handled under 1100 MHz alternative relative to 1200 MHz:

$$(Eq. 6) \text{ Impact}_{1100\text{MHz}} = \frac{\text{Connections}_{1200} - \text{Connections}_{1100}}{\text{Connections}_{1200}} = \frac{42 - 40}{42} = 4.76\%$$

C.4. Benefits derived from reduced latency (effect 3.4)

As a starting point, in a comparison of the technical performance regarding latency for Wi-Fi 6, a Wi-Fi Alliance analysis refers to field tests conducted by Qualcomm in a home environment where the data delivery response is reduced by 40% (see Table C-11 and Equation 7).

Table C-11. Latency scenarios in use cases for Wi-Fi 6 environments

⁶¹ Calculated as 10 BTS (Bits per Symbol) * 0.83 (error correction) * (Resource units/0.000136 sec)/100000

Environments	Latency (ms) Download (DL)	% Latency reduction
Household Wi-Fi5	15	40%
Household Wi-Fi 6	9	

Source: WiFi Alliance, "The Beacon" <https://www.Wi-Fi.org/beacon/rolf-de-vegt/reduced-latency-benefits-of-Wi-Fi-6-ofdma>

$$(Eq. 7) \quad \Delta L = \frac{L_{WiFi} - L_{Wi-Fi6}}{L_{Wi-Fi6}} = \frac{15 - 9}{15} = \frac{6}{15} = 40\%$$

Although the Wi-Fi Alliance refers to the latency of office environments with Wi-Fi 6, it is assumed that in relation to the Wi-Fi 6E standard there is a similar variation in latency, since it has the same channelization characteristics, although with greater bandwidth, which achieves the same theoretical speeds with an increase in the number of users. In this sense, the usage ratio between Wi-Fi 6 and Wi-Fi 6E could establish at most a latency similar to Wi-Fi 6 considering the use of the same channel width in the most used bands, currently, such as 2.4 GHz and 5 GHz.

Considering the lack of available information of tests differentiating between frequency bands in terms of their latency impact, we had to assume regarding the impact scenarios. In that sense, we rely on the reduction of latency data from Wi-Fi 6 (40%) and assume that use of the 6 GHz band will remain at constant speed and therefore the variable changing as a result of the different frequency allocation scenarios would be for the same number of users. Under the constant speed assumption, latency would change under frequency allocation scenarios: in other words, the 40% reduction would be the same under the frequency allocation alternative: 1100 MHz.

C.5. Enhanced IoT deployment (effect 3.5)

Considering that the number of M2M connections is the main variable in this case, the ratio of total IoT equipment is linked to the amount of assigned spectrum ($\Delta Spectrum$).

For the scenario of occupying the 6GHz band (1,200MHz) there would be no increase since Wi-Fi 6E under the 6 GHz band would occupy the same amount of spectrum. However, for the scenario of reduced allocation of 1100 MHz, the reduction of M2M connections would amount to 8.33% (see Equation 8).

$$(Eq. 8) \quad \Delta Spectrum = \frac{S_{1200\text{ MHz}} - S_{1100\text{ MHz}}}{S_{1200\text{ MHz}}} = \frac{1,200 - 1100}{1,200} = \frac{100}{1,200} = 8.33\%$$

C.6. Deployment of Augmented Reality/Virtual Reality solutions (effect 3.6)

The impact of different frequency allocation alternatives is assessed on the basis of Mehrnough, M., Hu, C. and Aldana, C. (2022) "AR/VR spectrum requirement for Wi-Fi 6E and beyond" paper⁶², which estimate the maximum number of AR/VR devices supported in a classroom of a given school, depending on whether 500 MHz or 1200 MHz are available for unlicensed use cases. This paper estimates, under a set of parameters of speed (50 Mbps) and latency (20 ms), through a simulation the maximum simultaneous number of headsets that can be used under both frequency allocation alternatives, keeping at a minimum the signal degradation.

⁶² Mehrnough, M., Hu, C. and Aldana, C. (2022) "AR/VR spectrum requirement for Wi-Fi 6E and beyond", *IEEE Access* (December)

According to the paper results, under 500 MHz allocation, the WI-FI can only handle four students in a school composed of four classrooms per floor. Under 1200 MHz, the WI-FI can handle up to 22 students within 14 classrooms per floor (or the whole school). The number of connected users diminishes by 81.82% from 1200 MHz to 500 MHz scenario. Using those two parameters, we estimate the reduction in the 1100 MHz to be 60% (see table C-12).

Table C-12. Reduction of AR/VR users under different frequency allocation alternatives

Spectrum available (MHz)	500	1100	1200
Household Wi-Fi5	4	8.8	22
Household Wi-Fi 6	81.82%	60%	-

Source: Telecom Advisory Services analysis

Then the impact on the 1100 MHz allocation depends on the total reduction of devices that the band contains relative to 1200 MHz; i.e. 60% (See Eq. 9).

$$(Eq. 9) \quad \Delta Devices = \frac{D_{1200\text{ MHz}} - D_{1100\text{ MHz}}}{D_{1200\text{ MHz}}} = \frac{22 - 8.8}{22} = \frac{13.2}{22} = 60\%$$

DC.7. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi (effect 4.1)

The increase in traffic due to the amount of spectrum assigned in the 6 GHz band has a direct influence on the reduction of CAPEX due to the overflow of mobile traffic to Wi-Fi networks. It is possible to relate the average speed variation with this indicator to establish a relationship between CAPEX and Wi-Fi traffic (see example of equation 10 below).

$$(Eq. 10) \quad \Delta Spectrum = \frac{Speed_{1200\text{ MHz}} - Speed_{1100\text{ MHz}}}{S_{1200\text{ MHz}}} = \frac{3,602.94\text{ Mbps} - 3,136.03\text{ Mbps}}{3,602.94\text{ Mbps}} = \frac{466.91}{3,602.94} = 12.96\%$$

Table C-13 presents the impact of alternative scenario of frequency allocation.

Table C-13. Difference between frequency allocation scenario of the 6 GHz band

Frequency allocation scenario	Speed	320 maximum channels	Speed per connection	Difference with 1200 MHz
1200 MHz	1,200.98	3	3,602.94	-
1100 MHz	1045.34	3	3,136.03	12.96%

Source: Telecom Advisory Services analysis

That is, under 1100 MHz alternative, speed is the variable that allows us to establish an impact relationship between Wi-Fi network overflow traffic and the mobile network of 12.96%.

C.8. Revenues of Wi-Fi based Public Internet Service Providers (effect 4.2)

The main variable driving economic value of the 6 GHz band for WISPs is related to the number of public Wi-Fi access points. From a technical point of view, the 6 GHz band for outdoor use is

defined through the power characteristic of the equipment (*standard power*) occupying the UNII-5 (5925-6425: 500MHz) and UNII-7 (6525-6875: 350MHz) band classification. To determine the impact of the technological upgrade on the increase of connections, two variables must be taken into consideration: (i) the maximum number of outdoor channels and (ii) the number of connections by resource units and bandwidth (see Table C-14).

Table C-14. Number of connections by resource units and bandwidth

Resource Units \ MHz	20	40	80	160	320
26	9	18	36	72	144
52	4	8	16	32	64
102	2	4	8	16	32
242	1	2	4	8	16
484	-	1	2	4	8
980	-	-	1	2	4
1960	-	-	-	1	2
3920	-	-	-	-	1

Source: Telecom Advisory services analysis

In a 1200 MHz allocation scenario, the implied 102 resource units and three 320 MHz channels could serve a maximum of 96 connections. A reduction of 100 MHz in the amount of allocated frequency has not a negative impact in the number of connections due to in both scenarios there are 3 maximum channels of 320MHz, according to the values of table C-15.

Table C-15. Impact of decreasing frequency scenarios on the number of connections

	1100 MHz	1200 MHz
Maximum number of 320 MHz channels	3	3
Connections with 242 resource units	96	96
Reduction relative to 1200 MHz alternative	0%	-

Source: Telecom Advisory services analysis

In light of this, the impact on the 1100 MHz allocation depends on the reduction in the number of available connections compared to the full band (1200 MHz); i.e. 0% (see Eq. 11).

$$(Eq. 11) \quad Connections_{1100} = \frac{C_{1200} - C_{1100}}{C_{1200}} = \frac{96 - 96}{96} = 0\%$$

C.9. Manufacturing of Wi-Fi devices and equipment for residential use (effect 5.1)

It is possible that, in the ratio of total sales of locally manufactured residential equipment, only the sales of Access Points are linked to the number of indoor users. However, it would be necessary to validate whether only part of the percentage increase in users is applicable to this case. In that sense, while leaving the values that increase indoor users, it would be important to look for a market-related value rather than a technical one.

Under the 1100 MHz frequency allocation alternative, the reduction on the number of devices manufactured would be 8.33% (see Eq. 12).

$$(Eq. 12) \quad \Delta Spectrum = \frac{S_{1200\text{ MHz}} - S_{1100\text{ MHz}}}{S_{1200\text{ MHz}}} = \frac{1,200 - 1,100}{1,200} = \frac{100}{1,200} = 8.33\%$$

In this sense, the percentage increase in indoor users is linked to the estimated traffic generated and bandwidth by the adoption of each standard, which has a direct impact on the manufacturing of equipment for residential use (see Table C-16).

Table C-16. Impact of decreasing frequency scenarios on the number of devices

	Bandwidth (MHz)	Reduction relative to 1200 MHz
Full Band 6 GHz	1200	
1100 MHz	1100	8.33%

Source: Telecom Advisory services analysis

C.10. Benefits of firms in the AR/VR ecosystem (effect 5.4)

Similar to the C.6 item, the number of AR/VR devices that can be simultaneously connected depends on the amount of unlicensed spectrum in the 6 GHz band (see table C-17).

Table C-17. Reduction of AR/VR users under different frequency allocation alternatives

Available spectrum (MHz)	500	1100	1200
Connected users	4	8.8	22
Impact	81.82%	60%	

Source: Telecom Advisory Services analysis

C.11. Compilation of improvement ratios by source of economic value

The impact of the 1100 MHz WI-FI allocation option has been compiled in relation to the reduction in either broadband speed, latency, number of users, or spectrum capability.

Table C-18. Decrease of 1100 MHz Wi-Fi allocation alternative relative to 1200 MHz (in percentage)

Sources	Effects	1100 MHz decrease over 1200 MHz			
		Speed (Mbps)	Latency (ms)	# Users	Spectrum
1. Free Wi-Fi	1.1. Savings incurred by consumers by accessing free Wi-Fi in public sites				
	1.2. Free Wi-Fi service supporting the needs of the broadband unserved population			5.88%	
	1.3. Benefit to consumers enjoying higher speed from free Wi-Fi under Wi-Fi 6E, and Wi-Fi 7			5.88%	
	1.4. Benefit to consumers relying on Wi-Fi in educational institutions				
	1.5. Use of Wi-Fi in highly dense heterogeneous environments				
2. Residential Wi-Fi	2.1. Consumer benefit derived from faster broadband speed	12.96%			
	2.2. Home internet access for devices that lack an Ethernet port				
	2.3. Avoidance of inside wiring investment				
	2.4. Consumer benefit generated by use of residential Wi-Fi devices and equipment				
	2.5. Bridging the digital divide: use of Wi-Fi to increase coverage in rural and isolated areas			4.76%	
3. Enterprise Wi-Fi	3.1. Benefits derived from an increase in average speed				
	3.2. Benefits derived from reduced latency		40%		
	3.3. Savings in business Internet traffic transmitted through Wi-Fi				
	3.4. Avoidance of enterprise building inside wiring				
	3.5. Enhanced IoT deployment				8.33%
4. ISPs	4.1. Cellular networks CAPEX savings by off-loading traffic to Wi-Fi	12.96%			
	4.2. Revenues of Wi-Fi based Public Internet Service Providers			0%	
	4.3. Revenues of Wi-Fi based Wireless Internet service Providers			4.76%	
5. Wi-Fi ecosystem	5.1. Manufacturing of Wi-Fi devices and equipment for residential use				8.33%
	5.2. Manufacturing of enterprise Wi-Fi devices and equipment				
	5.3. Benefits of Firms in the IoT ecosystem				8.33%
	5.4. Benefits of firms in the AR/VR ecosystem				60%