Assessing the economic value of

6 GHz band in Brazil

April 2024

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This study was commissioned by the Dynamic Spectrum Alliance and was conducted between March and April of 2024; the authors are solely responsible for its contents. This material has been funded by the Foreign, Commonwealth & Development Office - Government of the United Kingdom; however, the views expressed do not necessarily reflect the UK Government's official policies.

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EXECUTIVE SUMMARY

In 2024, ANATEL initiated a public consultation, that among other things, asks questions following up on its 2021 decision to open the entire 6 GHz band to restricted radiation equipment. These questions appear to be motivated by a decision taken at WRC-23 and is premised by the notion that as the demand for wireless connectivity grows, access to the upper 6 GHz spectrum becomes important for Brazilian mobile operators to enhance 5G capacity. The purpose of this economic study is to provide an assessment of the economic value of the 6 GHz band to be derived by estimating three alternative regulatory frameworks. They are: First, keep the entire 1200 MHz of the spectrum for unlicensed use, as previously decided in 2021 and eventually authorize standard power devices that could operate indoor or outdoor under the control of an Automated Frequency Coordination system (AFC). Second, split the band between Wi-Fi and IMT (International Mobile Telecommunications), allocating a portion of it for unlicensed use and another one for use by telecommunication service providers. Third, allocate 1200 MHz for indoor use and the lower part of the band for outdoor use to unlicensed use, and the higher part of the band for outdoor use to IMT (from now on, labeled the "hybrid" option). For this study, in alternatives two and three, it is assumed that IMT would use 700 MHz, however, other ranges might be considered by ANATEL. The economic study does not represent all potential regulatory frameworks.

It is important to note that this study provides an update of an August 2020 report by Telecom Advisory Services assessing the value of opening the entire 6 GHz band for restricted radiation equipment.[1] While the original study covered the period 2020-2030 with actual data through 2019, the current estimate is based on actual data through 2023 (in some cases, even full year projections based on 1Q24), and includes an additional driver of economic value (the local production and use of Wi-Fi equipment).

The methodology used to develop estimates for the three alternatives is similar to the one used in the prior study, whereby the different sources of economic value were estimated independently and then aggregated within a single value (this allows cumulating GDP impact, with consumer and producer surplus[2]) (see table A). 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 restricted radiation equipment.

[1] Telecom Advisory Services (2020). *Avaliação do valor econômico do uso não licenciado na Faixa de 6 GHz no Brasil*. New York, agosto.

[2] 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 producer 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 Value of the 6 GHz Band in Brazil

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing line sharing in the WISP sector		Faster speed of access for WISP subscribers
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi		Consumer surplus from increasing speed
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, logistics, etc.)	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment	
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy	Margins of ecosystem firms involved in AR/VR deployment	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption		Consumer surplus from faster data download rate as enabled by faster broadband
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption		Consumer surplus from faster data download rate as enabled by faster broadband
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices)	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots	
Residential Wi-Fi Devices and equipment		Producer surplus derived from additional sales of residential Wi-Fi devices and equipment	Consumer surplus derived from additional sales of residential Wi-Fi devices and equipment

Source: Telecom Advisory Services analysis

Economic value of allocating the full 6 GHz band for restricted radiation equipment use

The cumulative economic value between 2024 and 2034 of allocating the full 6 GHz band for unlicensed use amounts to US$ 689.18, comprising US$ 482.77 in GDP contribution, US$ 119.14 in producer surplus and US$ 87.27 in consumer surplus (see table B).

Table B. Brazil: Economic value of allocating the full 6 GHz band for restricted radiation equipment use (2024-2034) (in US$ billions)

Sources of value	GDP contribution	Producer surplus	Consumer surplus
1. Enhanced coverage and improved affordability	$ 51.88		$ 2.88
2. Increased speed by reducing Wi-Fi congestion	$ 182.44		$ 53.86
3. Wide deployment of Internet of Things	$ 47.69	$ 61.09	
4. Reduction of enterprise wireless costs		$ 15.67	
5. Deployment of AR/VR solutions	$ 186.94	$ 26.62	
6. Enhanced deployment of municipal Wi-Fi	$ 10.74		$ 1.35
7. Deployment of Free Wi-Fi Hot Spots	$ 3.08		$ 2.17
8. Aligning spectrum decision with other advanced economies		$ 0.73	
9. Enhancing the capability for cellular off-loading		$ 3.24	
10. Wi-Fi Devices and equipment		$ 11.78	$ 27.01
TOTAL	$ 482.77	$ 119.14	$ 87.27

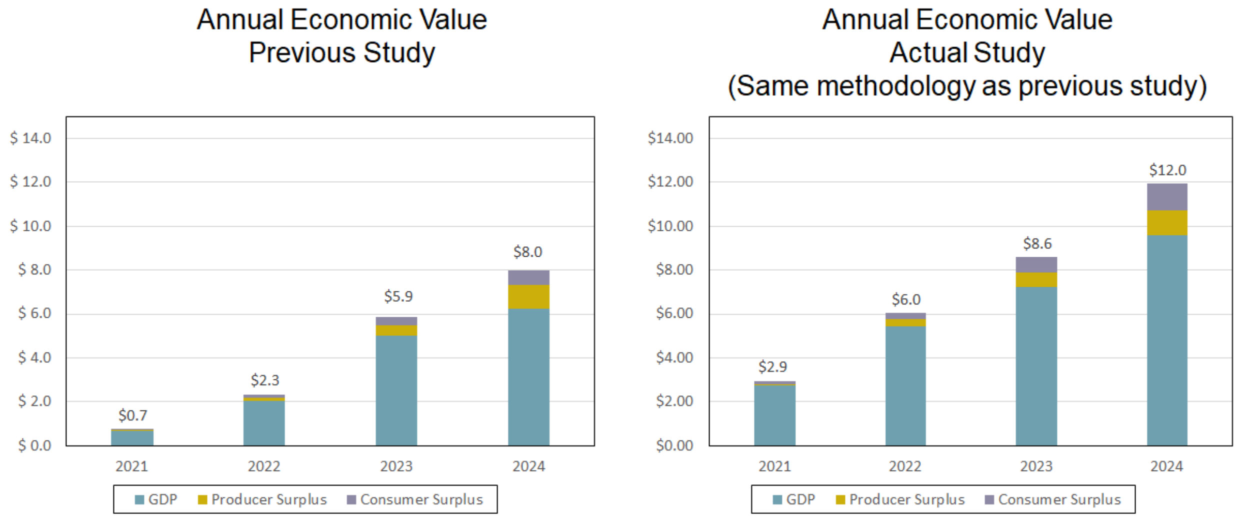
Source: Telecom Advisory Services analysis

The total economic value of allocating the full 6 GHz band for restricted radiation equipment use has significantly increased from our original estimate developed in the 2020 study as a result of dramatic changes that have taken place in the Brazilian broadband market:

- Quantum leap in the number of fixed broadband lines: while the number of lines estimated for 2023 in the prior study was 38,884,067, the actual value is 47,239,897 driven by the increase in growth rate triggered by the pandemic, the capability of service providers to respond to increased need, and policy incentives.
- Step function change in average fixed broadband speed: While the original study estimated that download speed would reach 66.04 Mbps by 2023, the actual value reported by ANATEL is 334.57 Mbps.
- Increase in the percentage of fixed broadband lines in excess of 150 Mbps: The original study estimated for Brazil a value of 4.37% in 2023; the actual percentage is 48.72%.

The dramatic increase in the percentage of lines with speeds higher than 150 Mbps has a multiplying effect in the value of addressing the residential Wi-Fi bottleneck by allocating the full 6 GHz band for restricted radiation equipment use. A comparison of economic value of both studies between 2021 and 2024 provides a perspective of the impact of the changes in the broadband market (see Graphic A).

Graphic A. Comparative estimates of economic value of full allocation of 6 GHz band for restricted radiation equipment use of both studies (2021-2024)



Source: Telecom Advisory Services analysis

Economic value if the lower 500 MHz is allocated for restricted radiation equipment use and the upper 700 MHz for use by IMT

The cumulative economic value of allocating 500 MHz for unlicensed use for the 2024-2034 period amounts to US$ 358.77, composed of US$ 241.08 in GDP contribution, US$ 55.81 in producer surplus and US$ 61.88 in consumer surplus.

Table C. Brazil: Economic value of allocating 500 MHz for restricted radiation equipment use (2024-2034) (in US$ billions)

Sources of value	GDP contribution	Producer surplus	Consumer surplus
1. Enhanced coverage and improved affordability	$ 37.81		$ 2.10
2. Increased speed by reducing Wi-Fi congestion	$ 95.12		$ 33.39
3. Wide deployment of Internet of Things	$ 19.87	$ 25.46	
4. Reduction of enterprise wireless costs		$ 7.94	
5. Deployment of AR/VR solutions	$ 77.89	$ 11.09	
6. Enhanced deployment of municipal Wi-Fi	$ 8.08		$ 1.01
7. Deployment of Free Wi-Fi Hot Spots	$ 2.31		$ 1.63
8. Aligning spectrum decision with other advanced economies		$ 0.00	
9. Enhancing the capability for cellular off-loading		$ 2.44	
10. Wi-Fi Devices and equipment		$ 8.87	$ 23.75
TOTAL	$ 241.08	$ 55.81	$ 61.88

Source: Telecom Advisory Services analysis

The decrease in economic value from the first alternative (US$ 330.41) is due to the following effects:

- 27% 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 500 MHz, which means that residential broadband access undergoes a bottleneck for lines in excess of 500 Mbps.
- More than half of IoT devices undergoes a limit in their indoor and outdoor access.
- 24.82% of total users of municipal and free hot spots are affected in Internet access due to the restriction of the upper part of the 6 GHz band for outdoor use.
- 58% 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.

Part of the negative economic impact of limiting access of the 6 GHz band for **restricted radiation equipment** use is mitigated by the benefits resulting from allocating 700 MHz to IMT: US$ 88.38 billion

- The GSMA estimates that the allocation of mid bands to IMT in Brazil would generate a GDP contribution of US$ 1 Billion in 2022, and US$ 41 billion in 2030.[3] Prorating this value to the 700 MHz in the 6 GHz band, and assuming that service on this band could only be launched in 2027 due to cleaning of the band and auction completion, yields a total GDP contribution between 2027 and 2034 of US$ 54.05 billion.
- Additionally, by gaining access to 700 MHz, wireless service providers could generate US$ 2.78 in producer surplus (primarily driven by IoT and AR/VR deployment) and US$ 19.92 billion in consumer surplus.
- Finally, it is estimated that auction proceeds for 700 MHz in the 6 GHz band could generate US$ 11.63 billion.

As a result, 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$447.15, of which US$ 358.77 is generated by the spectrum received for unlicensed use and US$ 88.38 billion would be generated by IMT.

Economic value if 1200 MHz for indoor use and 500 MHz for outdoor use are allocated for restricted radiation equipment use and 700 MHz band outdoor are allocated to IMT

The cumulative economic value for the 2024-2034 time period driven by the spectrum allocated for restricted radiation equipment use amounts to US$ 554.56, composed of US$ 387.04 in GDP contribution, US$ 82.65 in producer surplus and US$ 84.87 in consumer surplus (see table D).

[3] Source: GSMA, "Visao do mercado brasileiro – 5925-7125 MHz a faixa de 6 GHz" (May, 2022)

Table D. Brazil: Economic value of allocating 1200 MHz for indoor use and 500 MHz for outdoor use for restricted radiation equipment use (2024-2034) (in US$ billions)

Sources of value	GDP contribution	Producer surplus	Consumer surplus
1. Enhanced coverage and improved affordability	$ 37.81		$ 2.10
2. Increased speed by reducing Wi-Fi congestion	$ 182.44		$ 53.86
3. Wide deployment of Internet of Things	$ 27.04	$ 34.22	
4. Reduction of enterprise wireless costs		$ 15.67	
5. Deployment of AR/VR solutions	$ 129.37	$ 18.43	
6. Enhanced deployment of municipal Wi-Fi	$ 8.08		$ 1.01
7. Deployment of Free Wi-Fi Hot Spots	$ 2.31		$ 1.63
8. Aligning spectrum decision with other advanced economies		$ 0.45	
9. Enhancing the capability for cellular off-loading		$ 2.44	
10. Wi-Fi Devices and equipment		$ 11.45	$ 26.27
TOTAL	$ 387.04	$ 82.65	$ 84.87

Source: Telecom Advisory Services analysis

As expected, the erosion of value for unlicensed use in this alternative is primarily driven by the limitation imposed on outdoor usage, while some of the benefits for indoor access remain. However, when excluding indoor use of the spectrum to IMT service providers, their ability to generate economic value and mitigate value reduction of restricted radiation equipment use is considerably diminished:

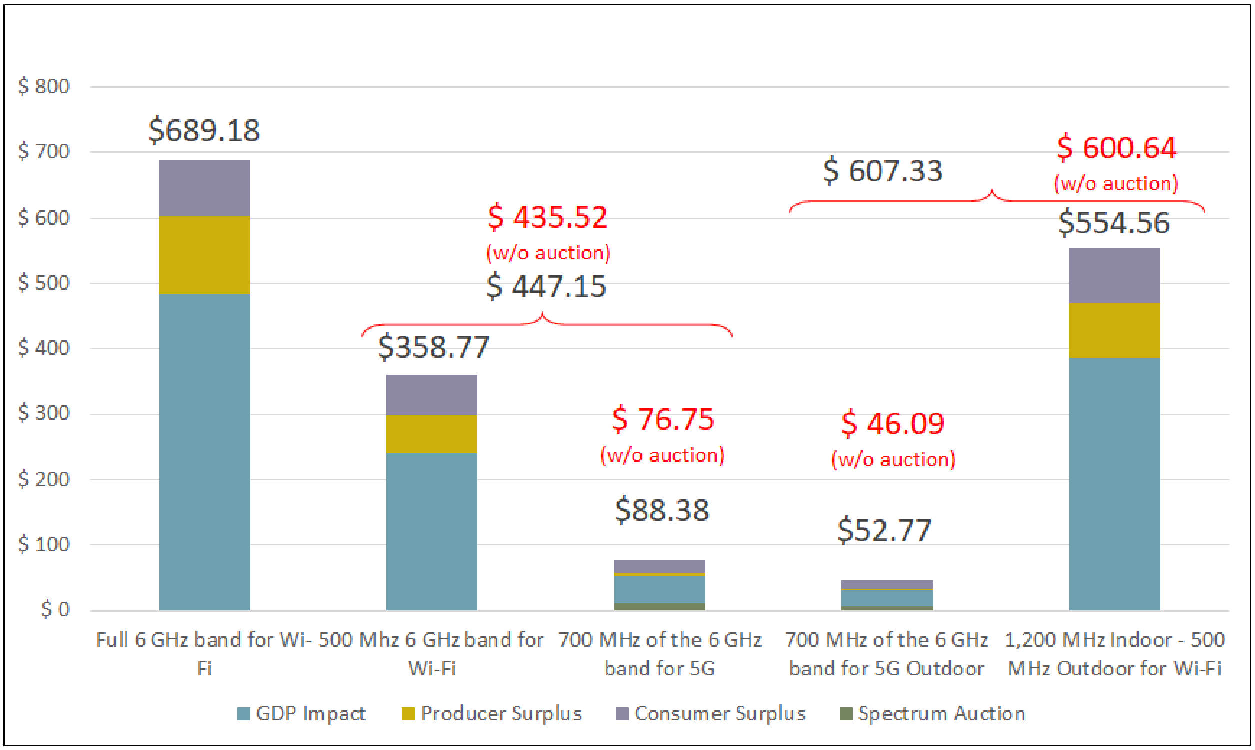
- Use case revenues of the 6 GHz band are limited given that they can only be realized through outdoor access (for example, 24.86% of IoT applications are indoor; 47.53% of AR/VR applications are indoors; only 50% of the expected FWA can be generated).
- Furthermore, this alternative requires a reduction of the IMT power to prevent interference. This study assumed that the reduction would be by approximately 15dB. When comparing how many users reach a specific SINR (signal to interference plus noise ratio), we estimate approximately a 35% reduction of the cell capacity outdoors.
- This results in economic value for IMT of US$ 31.11 in GDP contribution, US$ 1.87 billion in producer surplus, US$ 13.10 billion in consumer surplus, and US$ 6.69 billion in auction proceeds (note: auction value is diminished due to lower spectrum value).

As a result, total economic benefits of allocating 1200 MHz for indoor use and 500 MHz for outdoor use for restricted radiation equipment use and 700 MHz band outdoor to IMT is US$ 607.33.

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 restricted radiation equipment (see Graphic B).

Graphic B. Comparative economic value of the three regulatory alternatives



Source: Telecom Advisory Services analysis

As indicated in graphic B, values for the IMT allocation are provided with and without spectrum auction estimated proceeds. Even if those are included in the total value estimate, the full allocation to restricted radiation equipment use is US$242.03 billion higher than the partial allocation and US$81.85 billion than the "hybrid" alternative.

Furthermore, considering the current availability of 6 GHz certified devices, relative to the three-year lag of IMT in launching service in the band, Wi-Fi has the advantage of generating immediate economic impact and presents larger potential to increase coverage in rural and underserved areas.

These advantages occur, even without considering the costs to IMT generated by spectrum refarming, such as having to relocate incumbent 6 GHz fixed service links to other spectrum bands.

1. INTRODUCTION

On May 6, 2020, the Board of Directors of ANATEL, the Brazilian regulatory agency, approved changes to its Restricted Radiation Radio Communications ("RRRC") Equipment regulation to allow so-called "unlicensed" operations in the 5.925-7.125 GHz frequency band. Additionally, ANATEL staff provided the Board with technical rules for RRRC equipment operating in this frequency range.[4] The regulator also drafted rules to implement the decision, including applicable power limits and rules to protect current spectrum holders from harmful interference for the classes of 6 GHz devices authorized. ANATEL also decided to extend the power limits applicable to short-range devices that operate in the 5150–5350 MHz band, including Wi-Fi routers. These changes were documented under Resolution 726, with the modifications taking effect on September 1, 2020. Furthermore, ANATEL issued guidelines for marking the identification of ANATEL homologation in telecommunications products on July 31, 2020, through Act No. 4088, which outlines the requirements for the identification of ANATEL approval on products. The 25th of February 2021, the board of commissioners of ANATEL decided to open the complete 5925-7124 MHz band (6 GHz band) for unlicensed access by restricted radiation devices.

In 2024, ANATEL initiated a public consultation, that among other things, asks question following up on its 2021 decision to open the entire 6 GHz band to restricted radiation equipment. These questions appear to be motivated by a decision taken at WRC-23 and is premised by the notion that as the demand for wireless connectivity grows, access to the upper 6 GHz spectrum becomes important for Brazilian mobile operators to enhance 5G capacity. The purpose of this economic study is to provide an assessment of the economic value of the 6 GHz band to be derived by estimating three alternative regulatory frameworks. They are: First, keep the entire 1200 MHz of the spectrum for restricted radiation equipment, as previously decided in 2021 and eventually authorize standard power devices that could operate indoor or outdoor under the control of an Automated Frequency Coordination system (AFC). Second, split the band between Wi-Fi and IMT (International Mobile Telecommunications), allocating a portion of it for restricted radiation equipment use and another one for use by telecommunication service providers. Third, allocate 1200 MHz for indoor use and the lower part of the band for outdoor use to restricted radiation equipment use, and the higher part of the band for outdoor use to IMT (from now on, labeled the "hybrid" option). For this study, in alternatives two and three, it is assumed that IMT would use 700 MHz, however, other ranges might be considered by ANATEL. The economic study does not represent all potential regulatory frameworks.

The purpose of this study is to provide an updated assessment of the economic value of the 6 GHz to be derived by estimating three regulatory alternatives:

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[4] See https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=06/05/2020&jornal=515&pagina=13.

- An assessment of the value of opening full 6 GHz band for restricted radiation equipment use: In August 2020, Telecom Advisory Services submitted a report assessing the value of opening the entire 6 GHz band for restricted radiation equipment.[5] The current study provides an update of the different drivers of economic impact by relying on actual data since 2019 and includes an additional driver of economic value (the local production and use of Wi-Fi equipment). While the original study covered the period 2020-2030 with actual data through 2019, the current report is based on actual data through 2023 (in some cases, even full year projections based on 1Q24).
- An estimation of the economic value if the 6 GHz band were to be split between Wi-Fi and IMT, allocating the lower 500 MHz for restricted radiation equipment use and the upper 700 MHz band for use by telecommunication service providers.
- A quantification of value if the 6 GHz band if 1200 MHz for indoor use and the lower part of the band for outdoor use were to be allocated for restricted radiation equipment use and the higher 700 MHz band outdoor were to be allocated for use by IMT (the "hybrid" option)

Figure 1-1 depicts the three regulatory alternatives to be assessed in this study.

Figure 1-1. Alternatives to be assessed in the current report

	Indoor	Outdoor
Lower part (500 MHz)	A	
Upper part (700 MHz)	B	C

ALTERNATIVE 1: FULL BAND TO WI-FI	ALTERNATIVE 2: 500 MHZ TO WI-FI	ALTERNATIVE 3:FULL INDOOR AND 500 MHZ OUTDOORS
Keep the entire band for WiFi, that expands the potential for WiFi 6E and WiFi 7 development indoors and outdoors, enhancing their transmission capacity	Divide the band between WiFi and IMT (International Mobile Telecommunications), that would enable a new auction for the development of 5G and 6G	Divide the band between WiFi and IMT, but allowing full use for WiFi indoors, which would restrict its use outdoors, thus it's a possibility that requires further studies
A + B +C	A	A + B

Source: Telecom Advisory Services analysis

The time horizon for quantifying economic value of the three alternatives is 2024-2034. In addition, for reference the report includes the calculation for the impact for allocating the 1,200 MHz to restricted radiation equipment use between 2020 and 2023 to underline the changes that have occurred since our prior study.

At the aggregate level, the methodology relied upon in this study is exactly the same as the one used in our prior study, whereby the different sources of economic value were estimated independently and then aggregated within a single value (this allows cumulating GDP

[5] Telecom Advisory Services (2020). *Avaliação do valor econômico do uso não licenciado na Faixa de 6 GHz no Brasil*. New York, agosto.

impact, with consumer and producer surplus). Along those lines, we proceeded to identify the sources of economic value, estimate their impact, and then combine them.

Chapter 2 delves into the evolution and benefits of opening the full 6 GHz band for restricted radiation equipment use, detailing changes since 2019-2020 and the associated economic value. More specifically, it quantifies the economic benefits of allocating the 1,200 MHz for restricted radiation equipment purposes, covering improvements in broadband coverage, affordability, speed, Internet of Things deployment, reductions in enterprise wireless costs, AR/VR solutions deployment, municipal Wi-Fi enhancements, free Wi-Fi spots, alignment with global spectrum decisions, cellular off-loading enhancements, and the impact on Wi-Fi devices and equipment. Chapter 3 shifts the focus to the economic implications of dedicating the lower 500 MHz of the band to restricted radiation equipment use, reiterating similar benefits as discussed in Chapter 2 but within the context of this narrower allocation. In addition, it quantifies the economic value of allocating the upper 700 MHz to IMT. Chapter 4 quantifies the value of the hybrid alternative. First, it considers the impact of allocating the full 1,200 MHz for indoor use and 500 MHz for outdoor allocation to restricted radiation equipment use. Following this, it quantifies the value of the upper 700 MHz to outdoor-exclusive use by IMT. Finally, Chapter 5 concludes by summarizing the total economic value generated by different spectrum allocation strategies, offering a conclusive assessment based on the detailed analyses, and drawing the policy implications.

2. ECONOMIC VALUE OF ALLOCATING THE FULL 6 GHz BAND FOR RESTRICTED RADIATION EQUIPMENT USE

2.1. Changes in the Brazilian broadband space since 2019-20

Since the publication of Telecom Advisory Services 2020 report, the Brazilian telecommunications market has undergone significant changes in terms of four key performance variables:

- Dramatic increase in fixed broadband lines
- Exponential improvement in fixed broadband download speed
- Increase in the number of fixed broadband lines in excess of 150 Mbps
- Decrease of prices in mobile broadband service

These four changes have important implications for assessing the economic value of opening the full value of the 6 GHz band.

2.1.1. Increase in fixed broadband users

In the prior study, we estimated, based on ANATEL data for 2019, that Brazil had reached 32,914,496 fixed broadband users. In addition, we projected based on the National Broadband Plan, that the number of 2020 broadband lines was 34,072,608. We also assumed the growth of the lines up to 2030 based on historical trend documented by the same source. In fact, the growth starting in 2020 reflected both an enhancement of natural demand but, more importantly, the increase in growth rate triggered by the pandemic, whereby users needed to acquire broadband to support remote delivery of telework, e-commerce and telemedicine, among many services. Consequently, the growth path of fixed broadband departed significantly from our prior estimate (see table 2-1).

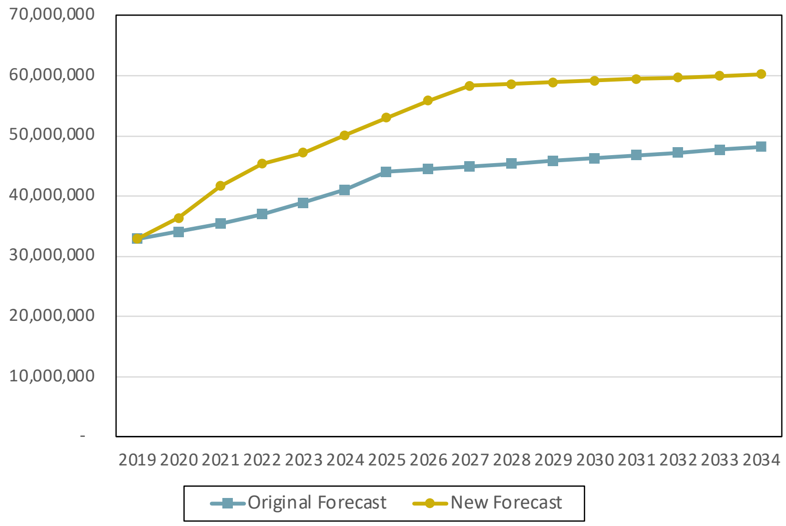
Table 2-1. Fixed broadband lines: Original forecast versus actual data (2019-2023)

	2019	2020	2021	2022	2023
Original forecast in 2020 study	32,914,496(**)	34,072,608(*)	35,431,290(*)	37,023,107(*)	38,884,067(*)
Actual data	32,906,998(**)	36,344,670(**)	41,657,433(**)	45,359,471(**)	47,239,897(**)

Sources: (*) TAS extrapolation based on the National Broadband Plan projections.
(**) ANATEL; the original 2019 estimate was restated in later documents.

This significant change resulted in a difference in forecast number of lines going forward (see graphic 2-1).

Graphic 2-1. Fixed broadband lines: Original forecast vs. new forecast based on actual data through 2023 (2023-2034)



Source: Telecom Advisory Services analysis based on ANATEL data

Notice that by the end of the period (2034), the difference between both forecasts in the total number of fixed broadband lines is more than 12 million lines. This change is significant because it increases the value of reducing residential Wi-Fi congestion by allocating the 6 GHz band for restricted radiation equipment use. In addition, ANATEL data[6] indicates that Wi-Fi use of terminating fixed broadband traffic amounts to 84.5%. This amount is higher than the number estimated in the previous study, which was based on CISCO data (60.9% for 2023).

2.1.2. Exponential improvement in fixed broadband download speed

In the 2020 study, since at the time ANATEL did not publish detailed data about average fixed broadband speed (we only had access to data about the distribution of broadband connections up to 34 Mbps), we relied on Ookla Speedtest, the crowd-sourcing platform, which estimated that average fixed broadband download speed for Brazil was 43.26 Mbps. The forecast in 2023, based on CISCO projections and the distribution of fixed broadband connections by range of download speed[7], was estimated by us to be 66.04 Mbps.

However, driven by an accelerated natural growth of demand and the additional boost of the pandemic, actual speeds departed significantly from the original forecast. The change could also have been caused by ANATEL's published data which is prone to be more precise than crowd-sourced estimates. More importantly, the deployment of FTTx and cable modem technology enabled broadband suppliers to deliver enhanced service at lower prices, therefore acting as an additional demand accelerator (see table 2-2).

[6] Reported in ANATEL (2023). *Pesquisa de Satisfacao e qualidade percibida 2023*.
[7] Source: ANATEL

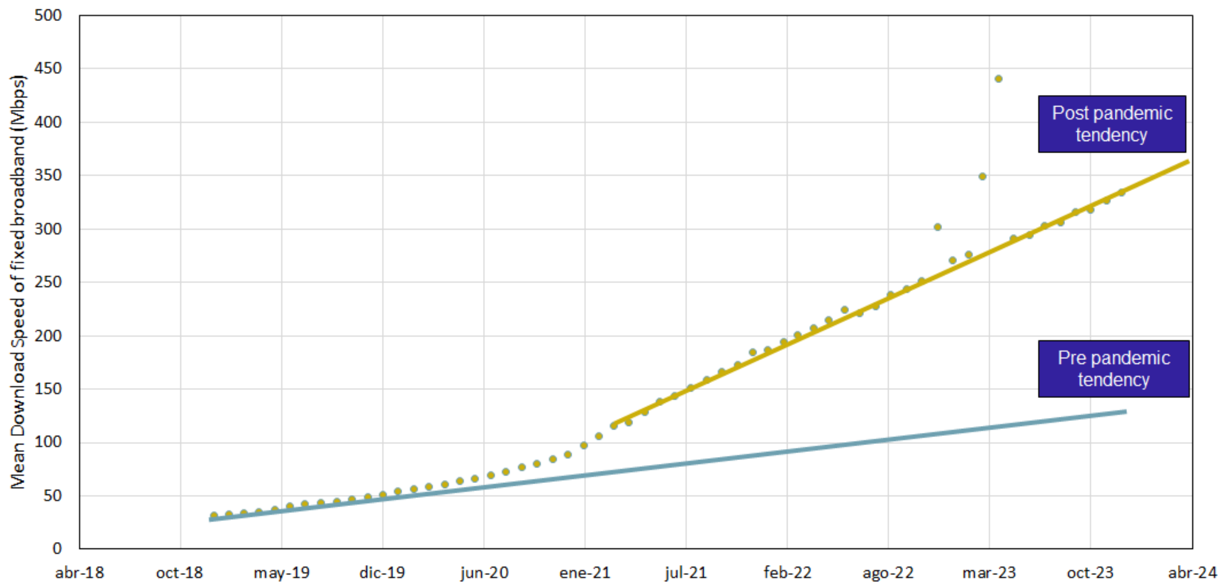
Table 2-2. Fixed broadband average download speed: Original forecast versus actual (Mbps) (2020-2023)

	2020	2021	2022	2023
Original forecast in 2020 study	43.26 (***)	48.27 (*)	54.43 (*)	66.04 (*)
Actual data	88.72 (**)	184.48 (**)	302.14 (**)	334.57 (**)

Sources: (*) TAS extrapolation based on historical growth rates by range of download speed (ANATEL) and CISCO projections
(**) ANATEL
(***) Ookla, calibrated with ANATEL distribution of broadband connections by range of download speed

Graphic 2-2 depicts the difference in growth vectors between the 2020 forecast and actual data.

Graphic 2-2. Average fixed broadband download speed (2019-23) (in Mbps)



Source: Telecom Advisory Services analysis based on ANATEL

As a consequence of the increase in average download speed, the number of lines in excess of 150 Mbps, a threshold driving a potential bottleneck if Wi-Fi routers do not gain access to the 6 GHz spectrum, has also increased dramatically.

2.1.3. Increase in the number of fixed broadband lines in excess of 150 Mbps

In the 2020 study, we estimated based on Cisco's Visual Network Index, that the percent of lines with speeds higher than 150 Mbps in Brazil was 0.89%[8]. In fact, using recently

[8] CISCO's VNI estimated that for 2023 9.4% of fixed broadband connections will be faster than 100 Mbps (CISCO VNI 2018-2023). Also, that percentage was estimated at 0.8% in 2018.

published ANATEL data of average download speed, distribution of connections by download speed (up to 34 Mbps) and the median download speed data from Ookla, allowed us to estimate the percentage in 2020 to be 15.50%[9] and in 2023 48.72%. As indicated in table 2-3, the 2023 value is ten times higher than the projection in the 2023 study (4.37%).

Table 2-3. Percent of fixed broadband connections>150 Mbps: Original forecast versus actual (Mbps) (2020-2023)

	2020	2021	2022	2023
Original forecast in 2020 study	0.89% (*)	1.05% (*)	2.22% (*)	4.37 % (*)
Actual data	15.50% (**)	28.42% (**)	33.65% (**)	48.72% (**)

Sources: (*) TAS estimation based on CISCO
(**) TAS estimation based on ANATEL and Ookla median download speed

As it will be shown later, the dramatic increase in the percentage of lines with speeds higher than 150 Mbps has a significant increase in the value of addressing the residential Wi-Fi bottleneck by allocating the full 6 GHz band for restricted radiation equipment use.

2.1.4. A decrease of prices in mobile broadband service

Our previous study predicted a gradual decrease in mobile broadband prices over the years, estimating a drop from $1.64 per GB in 2019 to $1.07 per GB by 2023. This forecast was based on the projection of the US historical price evolution. Actual data revealed a steeper decline than forecasted, particularly noticeable in 2023, where the price plummeted to $0.61 per GB, significantly lower than the anticipated $1.07. Table 2-4 presents a comparative analysis of the price per GB of mobile data from 2019 to 2023, juxtaposing original forecasts from the 2020 study against actual data.

Table 2-4. Price per GB of mobile data (2019-2023)

	2019	2020	2021	2022	2023
Original forecast in 2020 study	$ 1.64 (**)	$ 1.47 (****)	$ 1.33 (****)	$ 1.19 (****)	$ 1.07 (****)
Actual data	$1.64 (**)	$ 1.46 (***)	$ 1.31 (***)	$ 1.17 (*)	$0.61 (*)

Sources: (*) UIT data for a basket with 10 GB of mobile data
(**) A4AI
(***) Interpolation
(****) TAS projection using USA price evolution

The accelerated decline in mobile broadband prices diminishes the cross-elastic advantage of re-routing enterprise wireless traffic to Wi-Fi from wideband cellular.

2.2. Economic value by driver

[9] The estimation was based as follows: The percentage of connections exceeding 150 Mbps is estimated as the median speed (Source: Ookla), divided by the calculation speed of 150 Mbps, and further divided by 2, considering the median divides the connections into halves - one above and the other below the threshold speed. The evolution of this indicator is related to the percentage of connections exceeding 34 Mbps (Source: ANATEL), with the latter indicator always being lower. For instance, as of December 2023, according to ANATEL, 90.09% of connections exceed 34 Mbps, whereas, according to the applied formula, only 48.72% of connections exceed 150 Mbps.

Having completed our assessment of the changes in key value drivers since the 2020 study, we will now move to provide the estimates for each area based on forecasts between 2024 and 2034. Beyond GDP contribution, we add to this analysis by measuring the economic surplus triggered by the adoption of the technologies operating in the unlicensed network bands. The underlying assumption of this approach is that the unlicensed spectrum resource generates a shift both in the demand and supply curves resulting from changes in the production function of services as well as the corresponding willingness to pay. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is whether Wi-Fi, enabled by unlicensed spectrum, represents a positive contribution to wireless carriers' CAPEX and OPEX insofar as they can control their spending while meeting demand for increased wireless traffic. From an economic theory standpoint, the wireless 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. To quantify incremental surplus derived from the adoption of technologies operating in the 6 GHz band, we itemize the number of technologies and applications intricately linked to this environment. We complement the concept of producer surplus with an assessment of the consumer surplus., The estimate between 2024 and 2034 is also complemented with the assessment for the 2021-2023 period based on the new data available, to compare them with our prior estimation.

At the aggregate level, the methodology relied upon in this study is similar to the one used in the prior study, whereby the different sources of economic value were estimated independently and then aggregated within a single value (this allows cumulating GDP impact, with consumer and producer surplus[10]). Along those lines, we proceed to identify the sources of economic value, estimated their impact, and then combined them in the aggregate. The area of impact of each source of value varies (see table 2-5).

[10] We consider that cumulating 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 producer 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 be included in the GDP model estimates.

Table 2-5. Sources of Value of 6 GHz Band in Brazil

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in the WISP sector		Faster speed of access for WISP subscribers
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi		Consumer surplus from increasing speed
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, food processing, logistics, etc.)	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment	
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy	Margins of ecosystem firms involved in AR/VR deployment	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption		Consumer surplus from faster data download rate as enabled by faster broadband
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption		Consumer surplus from faster data download rate as enabled by faster broadband
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices)	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots	
Residential Wi-Fi Devices and equipment		Producer surplus derived from additional sales of residential Wi-Fi devices and equipment	Consumer surplus derived from additional sales of residential Wi-Fi devices and equipment

Source: Telecom Advisory Services analysis

2.2.1 Enhanced broadband coverage and improved affordability

The latest statistics for Brazil indicate a 2023 fixed broadband penetration of 62.23% (or 47,239,897 connections for 75,911,470 households)[11]. Based on the growth rate assumed by Statista Market Insights, an extrapolation to 2034 indicates that penetration will reach

[11] ANATEL. Plano de Dados Abertos da Anatel, available at: https://www.anatel.gov.br/paineis/acessos/banda-larga-fixa

74.94%. Although most ISPs provide fiber connections, wireless connections still play an important and stable role, as seen in table 2-6.

As reported by ANATEL, Brazilian WISPs operate 1,678,055 wireless connections in 2023. The slowest connection speed, under 512 Kbps, accounts for a minimal fraction of the total at 0.19%, with 3,189 lines. Most WISP lines fall within the 2 Mbps to 12 Mbps range, making up 47.41% of the total with 795,517 lines. Connections between 512 Kbps and 2 Mbps represent 22.45% of the total, with 376,665 lines. Higher speed categories, 12 Mbps to 34 Mbps, and above 34 Mbps, account for 12.76% and 17.20% of the total, with 214,106 and 288,578 lines respectively (see table 2-6).

Table 2-6. Brazil: WISP Lines (2023)

	Total	
	N	**%**
<512 Kbps	3,189	0.19%
512 Kbps-2 Mbps	376,665	22.45%
2 Mbps-12 Mbps	795,517	47.41%
12 Mbps – 34 Mbps	214,106	12.76%
>34 Mbps	288,578	17.20%
Total	1,678,055	100.00%

Source: ANATEL. Plano de Dados Abertos da Anatel*; Telecom Advisory Services analysis*

WISPs tend to serve predominantly lower income groups households: according to the CeTIC.br survey, most of WISP customers belong to the C, D, and E strata. In these segments, wireless technology is hardly substituted by other kind of access technology.

As a result of the lower income population concentration, WISP Wi-Fi lines are frequently shared among neighbors. According to the Cetic.Br survey[12], in 2023 16.37 % of households in Brazil access broadband by sharing a fixed broadband connection with a neighbor (see table 2-7).

Table 2-7. Brazil: Connection sharing of fixed broadband (2023)

Social segment	Sharing connections	No sharing	Fixed broadband adoption	Households	Sharing (% households)	Sharing (% FBB connections)
A	8,765	1,052,661	976,063	1,083,153	0.83%	0.90%
B	1,299,672	12,426,944	11,579,739	14,114,562	9.47%	11.22%
C	5,002,919	27,353,079	24,111,755	35,864,644	15.46%	20.75%
D+E	4,089,649	12,302,864	9,670,733	24,849,111	24.95%	42.29%
Total	10,401,005	53,135,548	46,338,290	75,911,470	16.37%	22.45%

Source: CGI.br/NIC.br, Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação (Cetic.br), Pesquisa sobre o uso das tecnologias de informação e comunicação nos domicílios brasileiros - TIC Domicílios 2023

[12] CGI.br/NIC.br, Centro Regional de Estudos para o Desenvolvimento da Sociedade da Informação (Cetic.br), Pesquisa sobre o uso das tecnologias de informação e comunicação nos domicílios brasileiros - TIC Domicílios 2023

The sharing percentage had increased from 16.02% in 2015. Considering that WISPs serve primarily the most disadvantaged population, rather than relying on the aggregate sharing factor for fixed broadband of 16.37%, we rely for the following analysis on the sharing ratio corresponding to the C, D, and E segments. Accordingly, we estimate that 26.92% of Brazilian households that purchase a WISP-based broadband connection in the C, D and E segments share the line with their neighbor(s). This means that for every line deployed by a WISP, an additional 0.27 lines need to be added[13].

Based on interviews with the WISP association[14], the total number of fixed wireless lines is declining due to a gradual migration of fixed wireless lines to fiber optics in the access portion of the networks[15]. Also, considering the evolution of the sharing ratio since 2019 for the households with lower incomes, we forecast this value though 2034 to be decreasing from the 2023 value of 26.92% to 19.44%. These two tendencies yield the future evolution of households served by WISPs going forward (see table 2-8).

Table 2-8. Brazil: WISP Lines (2021-2034)

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
WISP	1,792,577	1,852,756	1,678,055	1,623,568	1,570,849	1,519,843	1,470,493	1,422,745	1,376,548	1,331,851	1,288,605	1,246,763	1,206,280	1,167,111
Shared ratio	28.55%	27.75%	26.92%	26.13%	25.37%	24.63%	23.91%	23.22%	22.54%	21.88%	21.24%	20.63%	20.02%	19.44%
Total	2,304,447	2,366,894	2,129,704	2,047,818	1,969,363	1,894,181	1,822,121	1,753,042	1,686,808	1,623,289	1,562,363	1,503,914	1,447,831	1,394,009

Sources: ANATEL; Cetic.br; Telecom Advisory Services analysis.

As indicated in table 2-8, the gradual decline in fixed wireless connections yields a decreasing number of households served, evolving from 2.1 million in 2023 to 1.4 million in 2034.

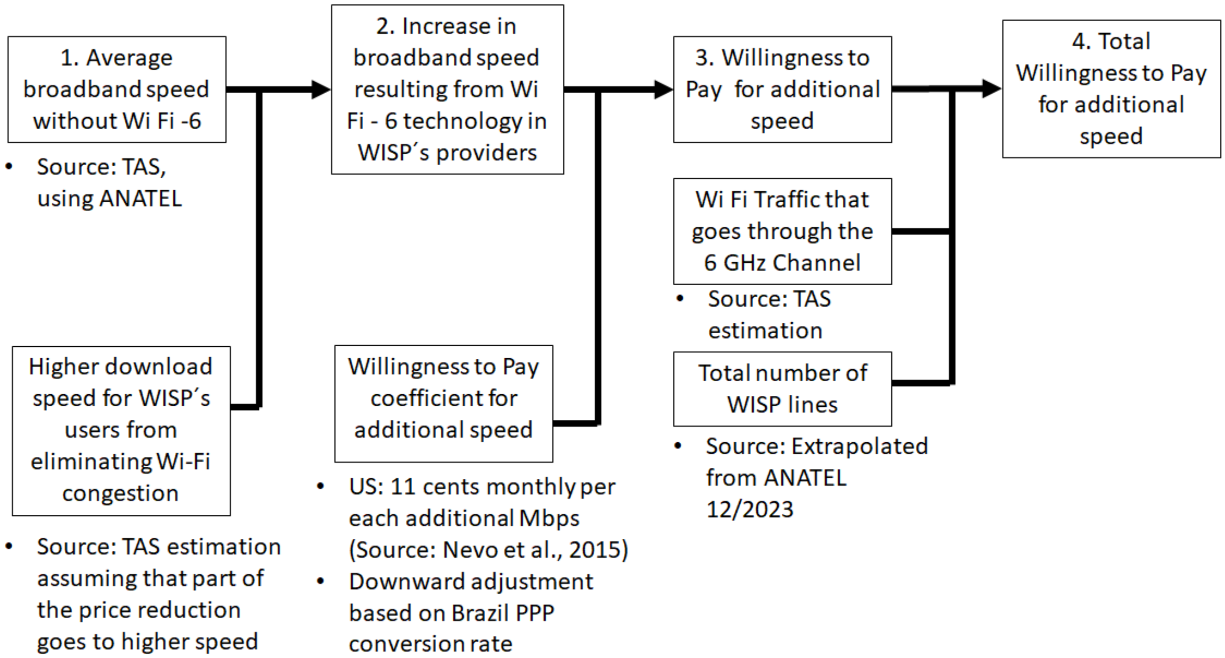
The 6 GHz decision would have an impact in two areas of economic value of WISPs: (i) growing consumer surplus of existing customers as a result of faster broadband service, and (ii) increasing affordability and, consequently, penetration of broadband, which in turn impacts the GDP. Each area will be reviewed in turn.

2.2.1.1. Impact of 6 GHz on consumer surplus of WISP customers

When WISPs have the opportunity to gain access to spectrum in the 6 GHz band, the consumer surplus for their subscribers results from an improvement in broadband speed as Wi-Fi congestion is addressed. In other words, the higher speed for the lines affected by the technology migration is multiplied by the willingness to pay, a value that is used to estimate consumer surplus (see figure 2-1).

[13] We believe this number might be conservative because interviews with the WISP association indicate that for every connection installed, up to 2 households would share it.
[14] Interview of Alex Jucius, General Director, Associaçao NEO.
[15] See also ABRINT (2018). *Plano de modernização e expansão de acessos com implantação de redes FTTH*. and NEO interview.

Figure 2-1. Methodology to estimate consumer surplus as a result of faster download speed in WISP connections



Source: Telecom Advisory Services

The starting point of this estimate is to calculate the difference in broadband speed of WISP lines yielded by accessing the 6 GHz spectrum. The multiplication of the speed increase by the willingness to pay (WTP) coefficient for incremental broadband speed yields an enhancement of consumer surplus by line, as estimated in primary research. Finally, the WTP per line is multiplied by the number of WISP lines (see table 2-9).

Table 2-9. Consumer surplus due to WISP user speed increase (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Average Download Speed	12.16	12.16	12.16	12.16	12.16	12.16	12.16	12.16	12.16	12.16	12.16
(2) New Average Download Speed	18.57	23.46	28.36	33.27	38.19	43.13	48.10	53.09	58.13	63.20	68.32
(3) Demand for average download speed	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93	46.93
(4) New Demand for average download speed	52.69	55.87	58.45	60.63	62.50	64.16	65.64	66.99	68.22	69.36	70.42
(5) Additional Monthly Consumer surplus	$5.76	$8.94	$11.52	$13.69	$15.57	$17.23	$18.71	$20.05	$21.29	$22.43	$23.49
(6) Additional Yearly Consumer Surplus	$69.11	$107.29	$138.27	$164.33	$186.85	$206.72	$224.51	$240.65	$255.45	$269.11	$281.82
(7) WISP Connections (Millions)	1.896	1.901	1.904	1.905	1.904	1.901	1.897	1.873	1.848	1.823	1.798
(8) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(9) Impact (US$ Billions)	$ 0.039	$ 0.076	$ 0.118	$ 0.164	$ 0.213	$ 0.265	$ 0.319	$ 0.361	$ 0.401	$ 0.442	$ 0.481

Sources: Telecom Advisory Services analysis.

Based on the calculations of table 2-9, total 2024-2034 projected cumulative consumer surplus impact resulting from increasing broadband speed by reducing Wi-Fi congestion for WISP users amounts to US$ 2.881billion.

2.2.1.2. Impact on GDP by increasing affordability and penetration of broadband from WISPs

The objective in this case is to estimate the impact on GDP of the change in broadband affordability and consequential broadband penetration within WISPs. To start with, the 6 GHz allocation to restricted radiation equipment use will improve the number of households being served per WISP access point. In theory, given the conventional economies of scale in telecommunications, the unit cost to serve a higher number of subscribers from a single point would reduce the unit OPEX. Furthermore, this reduction could be partially neutralized by the amortization of CAPEX to migrate the electronics to the new standard[16]. We estimate that OPEX could be reduced by around 60%, but only the 25% of that reduction could be transfered to lower prices (the rest should be invested in CAPEX). That situation also could happen with no change in nominal prices, but with a 15% price drop due to the projected increase in GDP, that would generate that the overall affordability of service at real prices will be higher (a real price decrease of 15%). This will allow consumers who have argued that pricing represented a barrier to adoption to acquire broadband service, to buy the service. In addition, the higher performance of Wi-Fi 6 will allow to maintain the number of sharing households. A higher broadband penetration will in turn have an impact on the Brazilian GDP. Figure 2-2 presents the methodology followed to develop this estimate.

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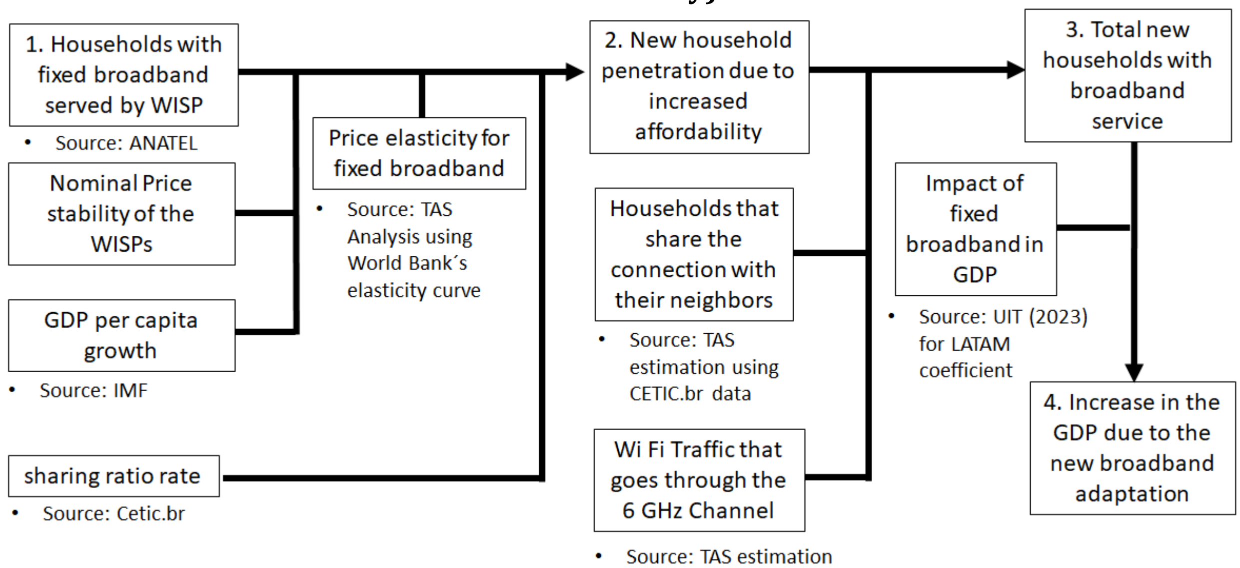
[16] On a side note, the experience of United States WISPs indicates that, if the spectrum allocated is adjacent to the 5 GHz bands originally used, the existing SDR equipment can be converted for use in the newly allowed band and can be adjusted to work in at least the lower band of 6 GHz. Of course, the use of current equipment may be subject to standards and protocols as well as an AFC that may not be possible with current equipment. Its "International" designation may also impact the availability for use.

Figure 2-2. Methodology to estimate GDP impact of increasing broadband affordability)



Source: Telecom Advisory Services

The starting point is the number of households served by Brazilian WISPs as depicted in table 3-3, evolving from 1,678,055 in 2023 to 1,167,111 in 2034 (with a high concentration of the latter number in rural areas). Also, we assume a 15% real drop in WISP prices, mostly due to an increase in GDP. Additionally, it should be acknowledged however that not all WISPs will migrate to Wi-Fi 6 immediately: we assume that 30% of lines will be impacted in 2024, reaching 95% in 2034. This yields the first effect of incremental lines due to enhanced affordability (see table 2-10).

Table 2-10. Brazil: New WISP lines resulting from increased affordability (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) New WISP adoption after price decrease (% households)	3.32	3.19	3.08	2.96	2.85	2.75	2.65	2.55	2.46	2.36	2.28
(2) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(3) Increase in WISP connections due to lower real prices (households that buy the service)	272,323	330,035	383,948	434,228	481,035	524,526	564,849	583,904	601,207	616,844	630,898
(4) Sharing %	26.13%	25.37%	24.63%	23.91%	23.22%	22.54%	21.88%	21.24%	20.63%	20.02%	19.44%
(5) Increase in WISP connections due to lower real prices (considering households that share the connection)	343,483	413,762	478,514	538,062	592,710	642,749	688,451	707,952	725,209	740,364	753,551

Sources: Telecom Advisory Services analysis.

The combination of the increase in lines due to the lower prices and the line sharing effect drives an increase in broadband penetration exclusively due to 6 GHz effect on Brazilian WISPs: up to 0.94% in 2034. Based on the coefficient of impact of fixed broadband on GDP calculated by the authors in research conducted for the International Telecommunication Union[17], the total GDP impact is estimated (see table 2-11).

Table 2-11. Brazil: GDP contribution of New WISP lines resulting from increased affordability (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(7) Increase in national broadband penetration	0.45%	0.54%	0.62%	0.69%	0.76%	0.82%	0.87%	0.89%	0.91%	0.93%	0.94%
(8) Impact of fixed broadband adoption in GDP	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492
(9) Increase in the GDP due to the new broadband adaptation (% GDP)	0.10%	0.12%	0.13%	0.14%	0.15%	0.16%	0.17%	0.18%	0.18%	0.18%	0.19%
(10) GDP (US$ Billion)	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
(11) Total impact in GDP (US$ Billion)	$ 2.315	$ 2.750	$ 3.168	$ 3.622	$ 4.186	$ 4.762	$ 5.352	$ 5.774	$ 6.206	$ 6.647	$ 7.098

Sources: Telecom Advisory Services analysis.

In addition, the potential extension of point-to-point backhauling could increase the WISP coverage in rural areas. According Cetic.br survey, there are 860,181 rural households that that do not acquire broadband service because of lack of coverage. If we assume that 6 GHz spectrum could allow WISPs to extend their coverage into the rural areas, it could yield at least an increase of the unserved, which would also result in incremental penetration in Brazil. However, considering that some equipment issues still need to be addressed (e.g. weatherproofing), this impact will not be included in the total effect.

In summary, the total cumulative impact on the GDP resulting from increased broadband penetration due to enhanced affordability and sharing is US$ 51.879 between 2024 and 2034.

2.2.2. Increase speed by reducing residential Wi-Fi congestion

As in the case of WISPs, the value to be generated by the increase in average wireless speed resulting from allocating spectrum in the 6 GHz band for all Brazilian broadband households relying on Wi-Fi connectivity in the premise translates into a contribution to the GDP and an increase in consumer surplus.

ANATEL reports that out of the 47,239,897 broadband lines (December 2023), 42,559,105 (or 90.09%) are in excess of 34 Mbps. Additionally, ANATEL indicates that the average download speed in December 2023 was 334.57 Mbps. This, as mentioned in section 2.1.1, represents an exponential increase in download speed.

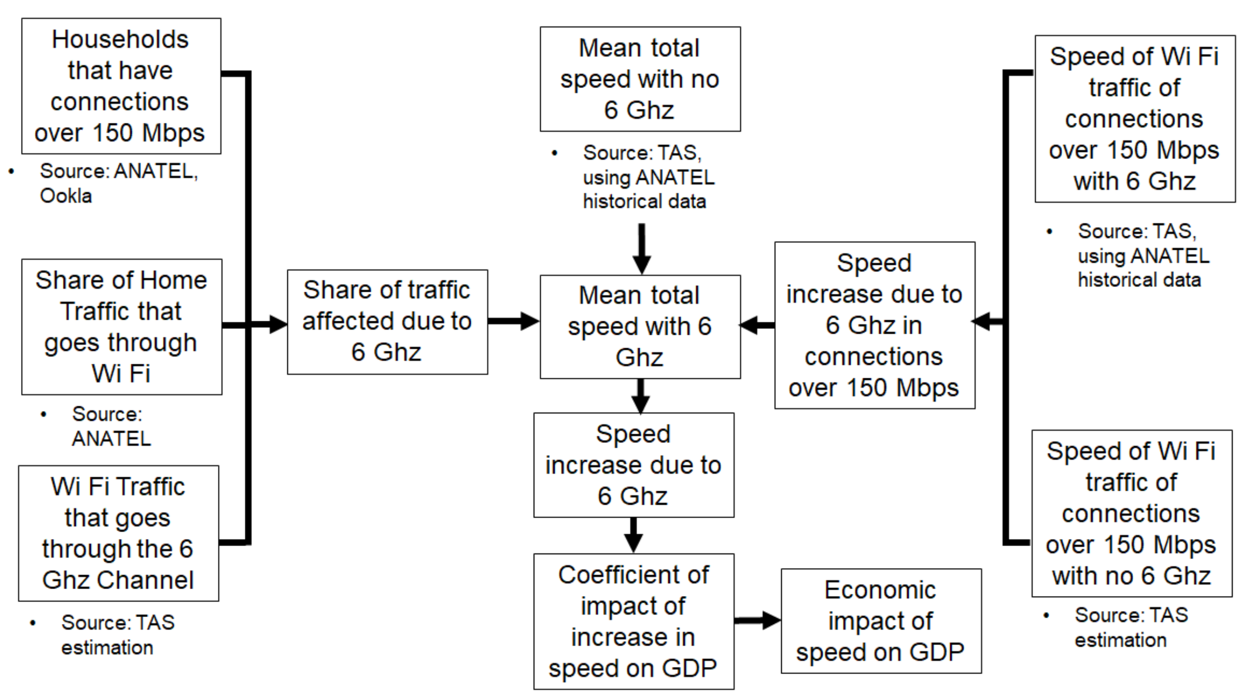
[17] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

As documented in appendix A.1, if a household acquires a 150 Mbps fixed broadband line, the router becomes a choke point in the network, and the speed experienced at the device level will be well below that delivered by the fixed network. Based on the statistics reviewed in section 2.1.1., considering that the median download speed is 151.28 Mbps in January 2024, the number of lines undergoing a potential bottleneck at the router level reaches around 50%. Given the increase in download speed of fixed broadband lines, if Wi-Fi performance is not improved by allocating additional spectrum for Wi-Fi, the in-premise devices are affected by a network bottleneck, and the speed experienced by a consumer at home will not be equivalent to that delivered by fixed networks. On the other hand, by allocating the 6 GHz spectrum to Wi-Fi, the speed will increase with the consequent economic effect.

2.2.2.1. Contribution to GDP by reducing Wi-Fi congestion

The objective is to estimate the impact on GDP of the future change in average broadband speed resulting from the improvement in speed for those households undergoing a Wi-Fi bottleneck (those purchasing fixed broadband plan in excess of 150 Mbps now and in the future). As explained above, despite the broadband capacity reaching the residence, these users would undergo a "bottleneck" in network performance as a result of spectrum-limited CPE (e.g. Wi-Fi router). Figure 2-3 presents the methodology followed to develop the economic estimate of allocating the 6 GHz band to restricted radiation equipment use.

Figure 2-3. Methodology to estimate GDP impact of reducing Wi-Fi congestion



Source: Telecom Advisory Services

The starting point of the methodology is to estimate the number of households in Brazil that have a connection over 150 Mbps that would undergo a Wi-Fi congestion problem as a result of routers relying only on the 2.4 GHz and 5.8 GHz bands. Based on the current spectrum allocation, dual router performance currently reaches 266.50 Mbps, which results from assuming an even split of traffic between the 2.4 GHz band (at 173 Mbps) and 5 GHz band (at 360 Mbps)[18]. The assignment of spectrum in the 6 GHz band would increase the average router capacity and reduce congestion, which in turn would augment the average broadband speed at the device level[19].

Given that not all households subscribe to a fixed broadband connection that undergoes a bottleneck at the CPE, we only consider in our analysis only those that have a connection in excess of 150 Mbps (which, when forecasting 2024 data, we assume to be 61.08% in 2024 increasing to 99.24% by 2034). In addition, not all traffic undergoes a router bottleneck, because a portion of it is being distributed through ethernet cabling, thereby avoiding Wi-Fi routers. This portion was estimated by ANATEL increasing from 82.85% in 2022 to 84.50% in 2023; for conservative purposes, we preserve that percentage stable up to 2034. Finally, it is assumed that in 2024, 30% of Wi-Fi traffic is distributed through a router with access to the 6 GHz band, reaching 95% by 2034 (see table 2-12).

Table 2-12. Brazil: Estimation of fixed broadband connections affected by 6 GHz decision (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Households that have connections over 150 Mbps (%)	61.08%	72.68%	84.28%	94.83%	96.19%	97.16%	97.86%	98.37%	98.75%	99.03%	99.24%
(2) Share of Home Traffic that goes through Wi Fi (%)	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%
(3) Traffic through the 6 GHz Channel (%)	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(4) Share of traffic affected due to 6 GHz (%)	15.48%	23.03%	32.05%	42.07%	48.77%	55.42%	62.02%	66.50%	70.93%	75.31%	79.67%

Sources: ANATEL; Ookla; Telecom Advisory Services analysis

This allocation will have an impact on Wi-Fi download speed of an incremental 350 Mbps in 2024, reaching 850 Mbps by 2034 (see table 2-13).

[18] See RAND study, table 5.2, p. 22, Scenario 1. This source is consistent with the analysis included in Appendix A.1. of this report.

[19] An important clarification: while this analysis is conducted for a router's total throughput, it is important to establish that the key driver is the perceived performance of a single user, which is less than 468.00 Mbps. Through the use of multiple bands and spatial streams, routers today commonly have total throughput capabilities well in excess of the speeds they can enable for individual devices. For example, a high-end 802.11ax device can, in theory, handle total throughput of 4.8 Gbps. The addition of 1,200 MHz in the 6 GHz band has an impact at the device level that could be higher than the total router throughput.

Table 2-13. Brazil: Estimation of fixed broadband speed in connections affected by 6 GHz decision

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(5) Speed of Wi Fi traffic of connections over 150 Mbps (no 6 GHz) (Mbps)	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00
(6) Speed of Wi Fi traffic of connections over 150 Mbps (with 6 GHz) (Mbps)	500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1000.00
(7) Speed increase due to 6 GHz (Mbps)	350.00	400.00	450.00	500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00

Sources: Telecom Advisory Services analysis

Having removed the spectrum bottleneck, the forecast of average fixed broadband household speed tends to grow unencumbered. This results in a speed increase of 54.19 Mbps for the average broadband connection in 2024, reaching 677.17 Mbps in 2034 (see table 2-14).

Table 2-14. Brazil: Increase in Speed resulting from 6 GHz allocation

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(9) Mean speed with no 6 GHz (Mbps)	359.11	399.69	426.11	438.49	459.36	473.59	481.48	497.62	509.89	517.86	521.71
(10) Mean speed with 6 GHz (Mbps)	413.30	491.81	570.33	648.84	727.57	806.09	884.60	963.12	1041.85	1120.36	1198.88
(11) Difference	15.09%	23.05%	33.84%	47.97%	58.39%	70.21%	83.73%	93.55%	104.33%	116.35%	129.80%

Sources: Telecom Advisory Services analysis

This increase is used to calculate the impact on GDP. The economic impact coefficient of incremental speed was calculated through an econometric model based on a historical data panel constructed for 49 countries with average data speeds higher than 40 Mbps for a time series between 2008 and 2019.[20] The data comprised 575 observations of quarterly data for:

- Average fixed broadband download speed[21](source: Speedtest Global Index)
- Gross Domestic Product (at current prices US$) (source: IMF)[22]
- Population (source: IMF)
- Fixed broadband adoption (percent of households with fixed broadband with a speed of at least 256 kbps) (source: International Telecommunication Union)
- Controls for country and time periods

The model includes:

[20] Of the 176 countries published now by Speedtest, we could only use a times series to run the model, which limited the number of countries to 159. Of those, we only run the model for those countries that exhibited an average fixed broadband speed higher than 40 Mbps at any point in time.

[21] The data panel on the Speedtest Global Index covers 159 countries.

[22] The models used GDP at current prices in US$ because the objective is to measure the impact of GDP in US$, without considering PPP as a deflator.

- a control for the previous quarter's GDP, to isolate the inertial effect of country growth
- download speed lagged by four quarters (1 year) to avoid a reversed causality effect
- changes in employment, to isolate the effect on GDP of the evolution of the labor market
- the country's investment rate (% of GDP) lagged by four quarters (1 year) to isolate the effect of investment on GDP
- the fixed broadband penetration rate to separate the broadband adoption effect from the speed effect

$$lnGDP_{it} = \beta_0 + \beta_1 lnGDP_{it-1} + \beta_2 lnDownload\ Speed_{it-4} + \beta_3 lnEmployment_{it} + \beta_4 lnInvestment\ Rate_{it} + \beta_5 lnFixed\ Broadband\ Adoption_{it} + \delta Country_i + \vartheta Time_t + \mu_{it}$$

We believe the inclusion of the country's investment rate as percent of GDP lagged by four quarters and broadband penetration rate and the model specification run on a worldwide panel help correct for any omitted variable bias. For example, the inclusion of fixed broadband adoption, which is correlated with broadband speed, allows for capturing a portion of the GDP impact that otherwise would be incorrectly attributed to broadband speed. With this in mind, the model yields the following results: every doubling of fixed broadband speed yields 0.73% in GDP growth (see Table 2-15).

Table 2-15. Impact of Fixed Broadband Download Speed on GDP

Impact on ln GDP	Download Speed higher than 40 Mbps
Ln Download Speed $_{t-4}$	0.00730 (0.00211) ***
Ln Employment $_t$	0.00458 (0.00165) ***
Ln Investment $_{t-4}$	-0.00085 (0.00481)
Control for Fixed Broadband adoption	0.00284 (0.00414)
Control for growth of previous GDP	0.99454 *** (0.00168)
Country Fixed Effect	Yes
Time Fixed Effect	Yes
Number of countries	49
Observations	575
R-Square	0.9438

***, **, * significant at 1%, 5% and 10% critical value respectively.
Source: Telecom Advisory Services analysis

By applying the coefficient of GDP impact of 0.73% for a 100% increase in speed, we estimate the overall GDP impact resulting from an increase in speed as a result of the allocation of the 6 GHz[23] (see table 2-16).

[23] It is important to note that, while the fixed broadband adoption coefficient is not statistically significant, this is due to the fact that the countries included in the sample have extremely high fixed broadband penetration; for these countries, the primary economic impact is not on adoption (e.g. late adopters will have less impact) but on speed.

Table 2-16. Brazil: Estimation of economic impact by reducing Wi-Fi congestion

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(12) Impact speed on GDP	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%
(13) Increase in GDP (%)	0.11%	0.17%	0.25%	0.35%	0.43%	0.51%	0.61%	0.68%	0.76%	0.85%	0.95%
(14) Brazil GDP Billion US$	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
(15) Impact (US$ Billions)	$ 2.495	$ 3.974	$ 6.119	$ 9.218	$ 11.826	$ 14.988	$ 18.840	$ 22.187	$ 26.081	$ 30.658	$ 36.051

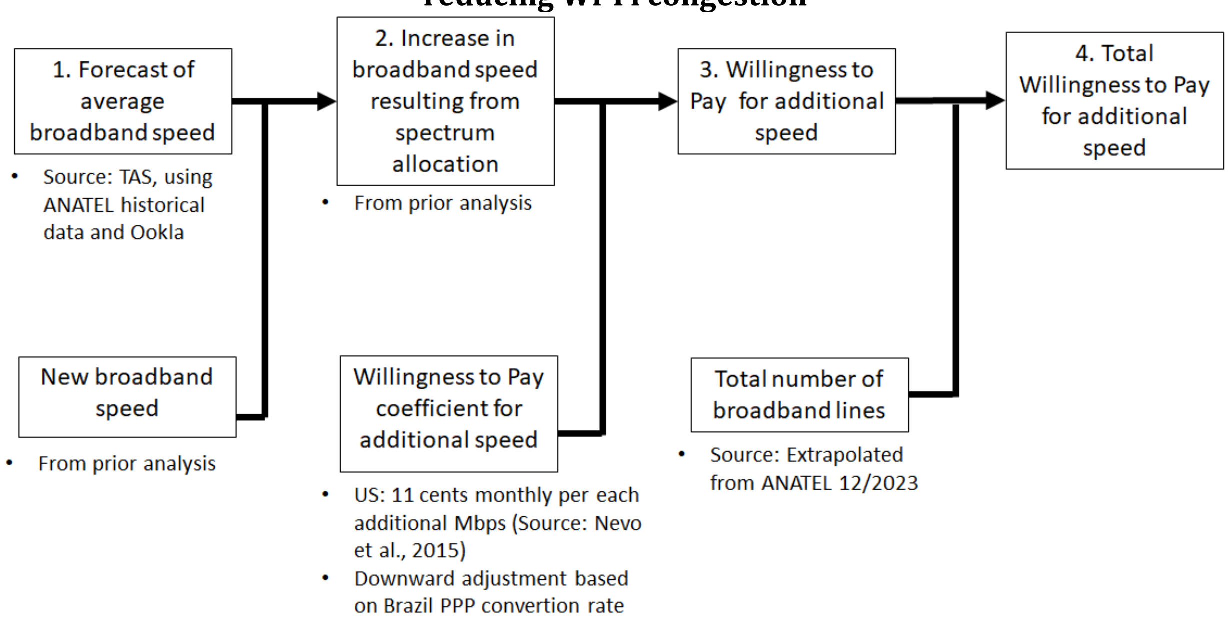
Sources: ANATEL; Cisco Virtual Networking Index

Total GDP contribution of the 6 GHz band allocation between 2024 and 2034 will reach US$182.438 billion.

2.2.2.2. Contribution to consumer surplus by reducing Wi-Fi congestion

The allocation of the 6 GHz band to restricted radiation equipment use will also have a net positive effect in terms of increased router throughput and therefore, average broadband speed. To reiterate, the consumer surplus to be estimated in this case should not be part of the GDP contribution but can be considered as part of the aggregate economic value. The key objective is to estimate the increase in consumers' willingness to pay derived from the acceleration in average broadband speeds, which would allow them to enhance their broadband consumption experience. The approach to estimate consumer surplus relies on the same calculations presented above in terms of the increase in Wi-Fi speed but factors them in terms of incremental wireless speed and the consequent impact on willingness to pay (see Figure 2-4).

Figure 2-4. Methodology to estimate Consumer Surplus contribution resulting from reducing Wi-Fi congestion

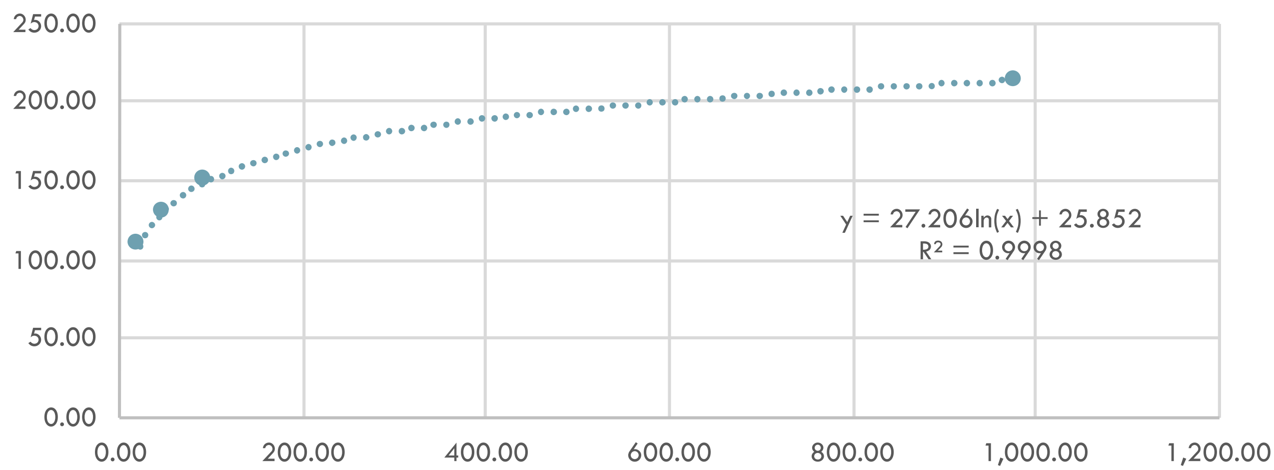


Source: Telecom Advisory Services

As calculated based on the broadband speed, the expected average broadband speed in 2024 in Brazil will be 359.11 Mbps. By addressing the bottleneck for users acquiring service in excess of 150 Mbps, average speed will increase to 413.30 Mbps, which results in a net increase in speed of 54.19 Mbps.

The next step is to estimate what consumers would be willing to pay for the additional speed. Given the lack of Brazilian willingness to pay data on broadband speed, the analysis conducted for this study relies on the data specifying the relationship between speed and consumer surplus generated in the Nevo et al. (2016) study for the United States.[24] This research provides empirical evidence stating that consumers' willingness to pay (WTP) to improve broadband speed by 1 Mbps ranges from nearly zero to just over US $5.00. The range is determined by heterogeneity in WTP, although the average value is US $2.02, and the median is US $2.48. Furthermore, the study also indicates that the higher speed does indeed generate substantial surplus. However, due to a declining marginal value of speed, speeds of more than 10 times those offered by the typical broadband plans imply only 1.5 times the surplus.[25] The data provided in the Nevo et al. (2016) study allows estimating a log curve depicting the relationship between willingness to pay and speed (see Graphic 2-3).

Graphic 2-3. Log Curve of relationship between broadband speed and willingness to pay (based on Nevo et al., 2016)



Note: Based on data points of table VII and table VI of Nevo et al., 2016.
Source: Nevo et al. (2016); Telecom Advisory Services analysis

According to the data of the Graphic 2-3, an increase in speed from 92.50 Mbps to 977.90 Mbps (ten times) increases willingness to pay from $149.90 to $212.90 (close to 1.5 times). The equation linking speed to consumer surplus in Graphic 2-3 was then used to estimate

[24] Nevo, A., Turner, J., and Williams, J. (Mar. 2016). "Usage-based pricing and demand for residential broadband", *Econometrica*, vol. 84, No.2, p. 441-443.
[25] This finding is consistent with the evidence provided in Liu et al. (2017), who found that the shape of households' valuation of broadband speed is concave. "Households are willing to pay about $2.34 per Mbps ($14 total) monthly to increase bandwidth from 4 Mbps to 10 Mbps, $1.57 per Mbps ($24) to increase from 10 to 25 Mbps, and only $0.02 per Mbps ($19) for an increase from 100 Mbps to 1000 Mbps."

the value to be derived by faster download speeds enabled by allocation of the 6 GHz band to restricted radiation equipment use. For this purpose, the difference between average download speed enabled by 6 GHz frequencies and current average download speed as increased annually at the current growth rate was multiplied by the coefficient of the log curve as depicted in the Graphic 2-3. This curve was downward adjusted by PPP conversion rate for Brazil (to adjust for local prices).

As in the case of the return to speed analyzed above, the annual consumer surplus generated by faster Wi-Fi will also be influenced by the same trends that evolve after 2023. These trends will affect the annual contribution to faster speeds resulting from the 6 GHz allocation as follows (see Table 2-17).

Table 2-17. Consumer Surplus from 6 GHz restricted radiation equipment (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Average Download Speed	359.11	399.69	426.11	438.49	459.36	473.59	481.48	497.62	509.89	517.86	521.71
(2) New Average Download Speed	413.30	491.81	570.33	648.84	727.57	806.09	884.60	963.12	1041.85	1120.36	1198.88
(3) Demand for average download speed	93.00	94.46	95.33	95.72	96.35	96.77	96.99	97.44	97.77	97.98	98.08
(4) New Demand for average download speed	94.91	97.28	99.30	101.05	102.61	104.00	105.27	106.43	107.50	108.49	109.41
(5) Additional Monthly Consumer surplus	$1.91	$2.82	$3.97	$5.33	$6.26	$7.24	$8.28	$8.99	$9.72	$10.50	$11.32
(6) Additional Yearly Consumer Surplus	$22.95	$33.87	$47.60	$63.99	$75.10	$86.86	$99.34	$107.84	$116.69	$126.02	$135.88
(7) Fixed Broadband Connections (Millions)	50.144	53.024	55.821	58.336	58.619	58.891	59.163	59.437	59.713	59.989	60.267
(8) Impact (US$ Millions)	$1,151	$1,796	$2,657	$3,733	$4,402	$5,115	$5,877	$6,410	$6,968	$7,560	$8,189

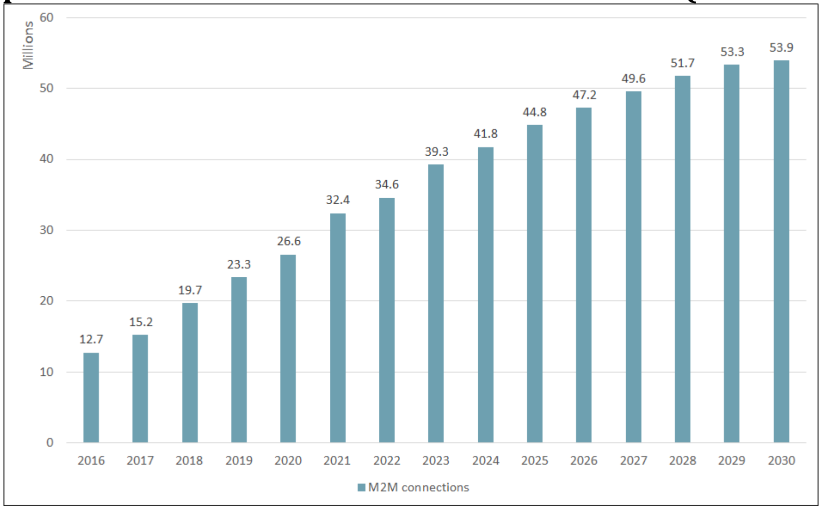
Source: ANATEL; Nevo et al. (2016); Telecom Advisory Services analysis

The increase of the average household in consumer surplus evolves from US$ 1,151 million in 2024 to US$ 8,189 million in 2034 (the households with bottleneck will have an increase higher than that, but the households with no bottleneck will have $0); this is the value multiplied by the total number of connections. In sum, total consumer surplus associated with the 6 GHz band between 2024 and 2034 will reach $53.86 billion.

2.2.3. Wide deployment of internet of things

Considering, that IoT devices have been deployed in Brazil for several years, the economic value estimation of “broader” deployment resulting from the combination of a significant amount of spectrum capacity requires teasing out the impact due to the natural growth of IoT based on the extrapolation of current penetration rates. M2M adoption, as a metric of IoT deployment (the only available indicator to measure IoT), has reached an installed base of 39.3 million in 2023 (see Graphic 2-4). These estimations from GSMA Intelligence are higher than the ones considered in the previous study from the same source (26.6 million in 2023).

Graphic 2-4. Brazil: Installed base of M2M devices (2016-2030)



Source: GSMA Intelligence

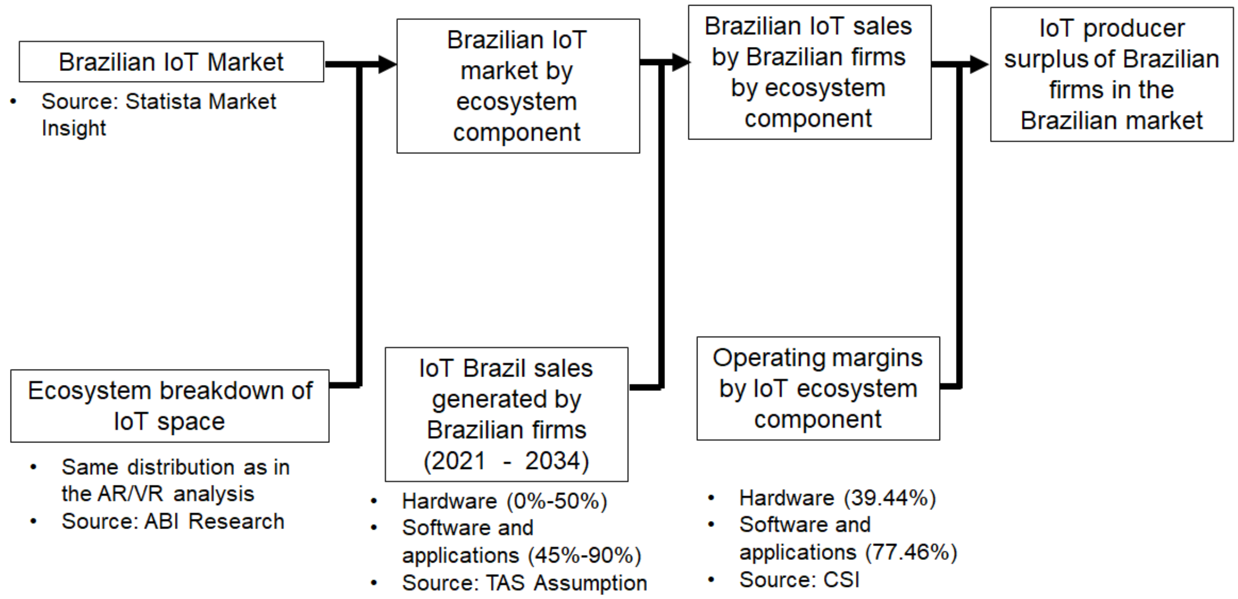
Also, the IoT Brazilian market in 2023 is estimated at US$9.87 billion[26]. The enhanced deployment of IoT due to the 6 GHz allocation to restricted radiation equipment use will trigger two economic effects: (i) the generation of producer surplus (i.e. margins) of Brazilian eco-system suppliers in the IoT segment, and (ii) the spillover of IoT on the efficiency of Brazilian industries.

2.2.3.1. Producer surplus of IoT eco-system firms

The objective is to calculate the impact that the allocation of the 6 GHz band would have in terms of expanding the IoT installed base, thereby generating producer surplus (i.e. operating margins) for the Brazilian suppliers of hardware, software, and systems integration (see figure 2-5)

[26] Source: Statista Market Insights. US$ 5.21 billion from industrial IoT; US$ 2.48 billion from consumer IoT; US$ 1.22 billion from Smart Cities and US$ 0.96 billion from healthcare IoT.

Figure 2-5. Methodology for estimating producer surplus from IoT Brazilian suppliers



Source: Telecom Advisory Services

Starting with a 2024 Brazilian IoT market revenues, we first estimate the portion that can be exclusively attributed to the additional spectrum allocation in 6 GHz. This estimate is calculated based on the difference between the previous projection of M2M devices from GSMA and the new one that considers an increase in the number of devices after the 2021´s ANATEL decision (see Table 2-18).

Table 2-18. Brazil: IoT market (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) IoT revenue in Brazil	$ 11.39	$ 12.75	$ 14.04	$ 15.37	$ 16.69	$ 17.56	$ 18.39	$ 19.18	$ 19.91	$ 20.60	$ 21.23
(2) Sales due to 6GHz Band (%)	22.11%	27.95%	34.46%	42.58%	51.28%	59.81%	66.81%	71.47%	74.58%	76.45%	77.25%
(3) Sales due to 6 GHz Band (in US$ billion)	$ 2.52	$ 3.56	$ 4.84	$ 6.54	$ 8.56	$ 10.50	$ 12.29	$ 13.71	$ 14.85	$ 15.75	$ 16.40

Source: Statista Market Insights; Telecom Advisory Services analysis

To calculate the producer surplus, we need to first estimate the breakdown of supplier components (hardware, software, and systems integration) (see table 2-19).

Table 2-19. Brazil: IoT market by ecosystem supplier (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	28.00%	27.48%	27.69%	26.75%	26.05%	24.52%	22.81%	21.18%	19.63%	18.17%	16.80%
Software and Apps	72.00%	72.52%	72.31%	73.25%	73.95%	75.48%	77.19%	78.82%	80.37%	81.83%	83.20%

Source: Statista Market Insights; Telecom Advisory Services analysis

In addition, the portion of the market to be served by Brazilian providers was also estimated (see table 2-20).

Table 2-20. Brazil: Share of IoT market served by Brazilian suppliers (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	20.00%	25.00%	30.00%	35.00%	40.00%	45.00%	50.00%	50.00%	50.00%	50.00%	50.00%
Software and Apps	60.00%	65.00%	70.00%	75.00%	80.00%	85.00%	90.00%	90.00%	90.00%	90.00%	90.00%

Source: Telecom Advisory Services analysis

Based on the operating margins by component, the producer surplus for Brazilian providers of IoT solutions was estimated (see table 2-21).

Table 2-21. Brazil: Producer surplus of Brazilian IoT suppliers (in US$ billion) (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	$ 0.06	$ 0.10	$ 0.16	$ 0.24	$ 0.35	$ 0.46	$ 0.55	$ 0.57	$ 0.57	$ 0.56	$ 0.54
Software and Apps	$ 0.84	$ 1.30	$ 1.90	$ 2.78	$ 3.92	$ 5.22	$ 6.61	$ 7.53	$ 8.32	$ 8.98	$ 9.51
Total	$ 0.90	$ 1.40	$ 2.06	$ 3.03	$ 4.27	$ 5.68	$ 7.16	$ 8.10	$ 8.90	$ 9.55	$ 10.06

Source: CSI Insights; ABI Research; Telecom Advisory Services analysis

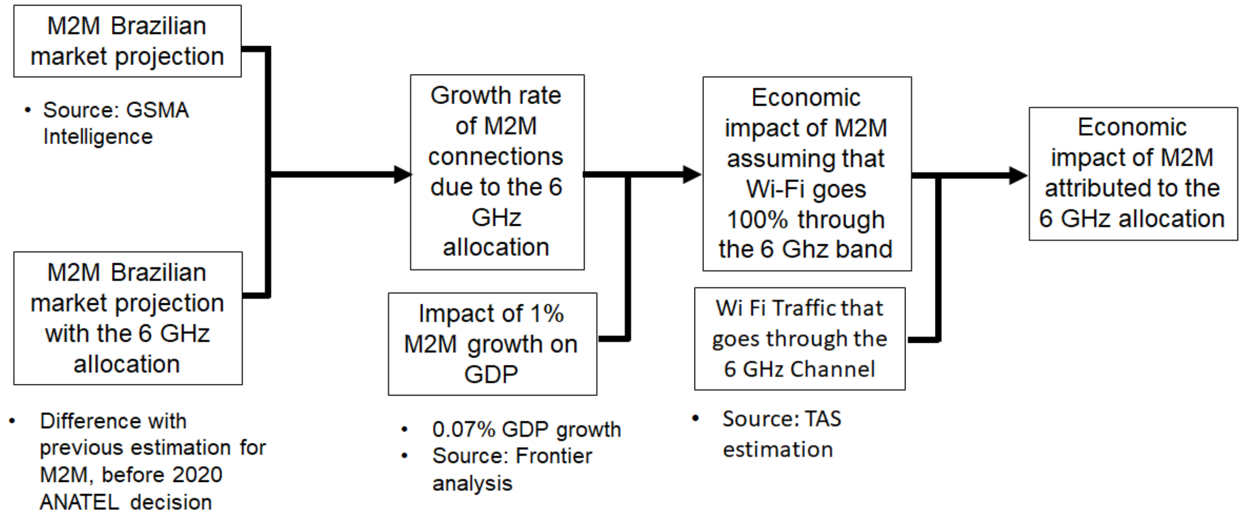
Based on the sum of annual values, the total cumulative value of producer surplus driven by sales of IoT by Brazilian firms in Brazil between 2024 and 2034 amounts to US$61.09 billion.

2.2.3.2. Spillover of IoT deployment propelled by 6 GHz allocation in Brazil

IoT adoption contributes to GDP growth through the multiplicity of use cases that improve efficiency in processes such as preventive maintenance and production monitoring. To estimate this, we rely on a coefficient of GDP impact calculated through an aggregate simple production function that estimates that a 10% rise in M2M connections results in annual increases in GDP of between 0.3% and 0.9% (see figure 2-6).[27]

[27] *See* Frontier Economics (2018). *The economic impact of IoT: putting numbers on a revolutionary technology.*

Figure 2-6. Methodology for estimating producer surplus from IoT Brazilian suppliers



Source: Telecom Advisory Services

By relying on the middle coefficient of the GDP impact contribution (0.7% for each 10% of the installed base), we estimate that in 2024, the impact of IoT would be 0.60% of GDP. Considering that Brazilian GDP in 2024 will reach US$2,265 billion (source: IMF), it is estimated that the IoT impact for 2024 would reach $3.06 billion (see Table 2-22).

Table 2-22. Brazil: IoT Spillover (in US$ billion) (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Brazil with no 6 Ghz	32,505,883	34,888,997	36,774,470	38,600,821	40,272,350	41,493,355	41,982,832	42,175,526	42,250,844	42,280,202	42,291,632
(2) Growth Rate (%)	6.34%	7.33%	5.40%	4.97%	4.33%	3.03%	1.18%	0.46%	0.18%	0.07%	0.03%
(3) Brazil with 6 Ghz	41,764,359	44,826,243	47,248,745	49,595,285	51,742,907	53,311,684	53,940,576	54,188,154	54,284,925	54,322,644	54,337,330
(4) Growth Rate (%)	6.34%	7.33%	5.40%	4.97%	4.33%	3.03%	1.18%	0.46%	0.18%	0.07%	0.03%
(5) Growth due to 6.0 Mhz (%)	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%	28.48%
(6) Impact of 1% M2M Growth on GDP	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%
(7) Use of the 6 Ghz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(8) Impact on GDP (%)	0.60%	0.75%	0.90%	1.05%	1.20%	1.35%	1.50%	1.60%	1.69%	1.79%	1.89%
(9) Brazil GDP Billions of US$	2,265	2,362	2,477	2,632	2,774	2,924	3,082	3,249	3,425	3,610	3,805
(10) Total Impact (US$ Billion)	$ 13.55	$ 17.66	$ 22.22	$ 27.55	$ 33.19	$ 39.36	$ 46.09	$ 51.82	$ 58.04	$ 64.77	$ 72.07
(11) Direct Impact (US$ Billion)	$ 2.52	$ 3.56	$ 4.84	$ 6.54	$ 8.56	$ 10.50	$ 12.29	$ 13.71	$ 14.85	$ 15.75	$ 16.40
(12) Total Indirect Impact (US$ Billion)	$ 11.03	$ 14.10	$ 17.38	$ 21.01	$ 24.63	$ 28.85	$ 33.81	$ 38.12	$ 43.19	$ 49.03	$ 55.66
(13) Indirect Impact (US$ Billion)	$ 3.06	$ 3.07	$ 3.28	$ 3.63	$ 3.62	$ 4.22	$ 4.95	$ 4.31	$ 5.07	$ 5.84	$ 6.64

Source: GSMA Intelligence; Frontier Economics; Telecom Advisory Services analysis

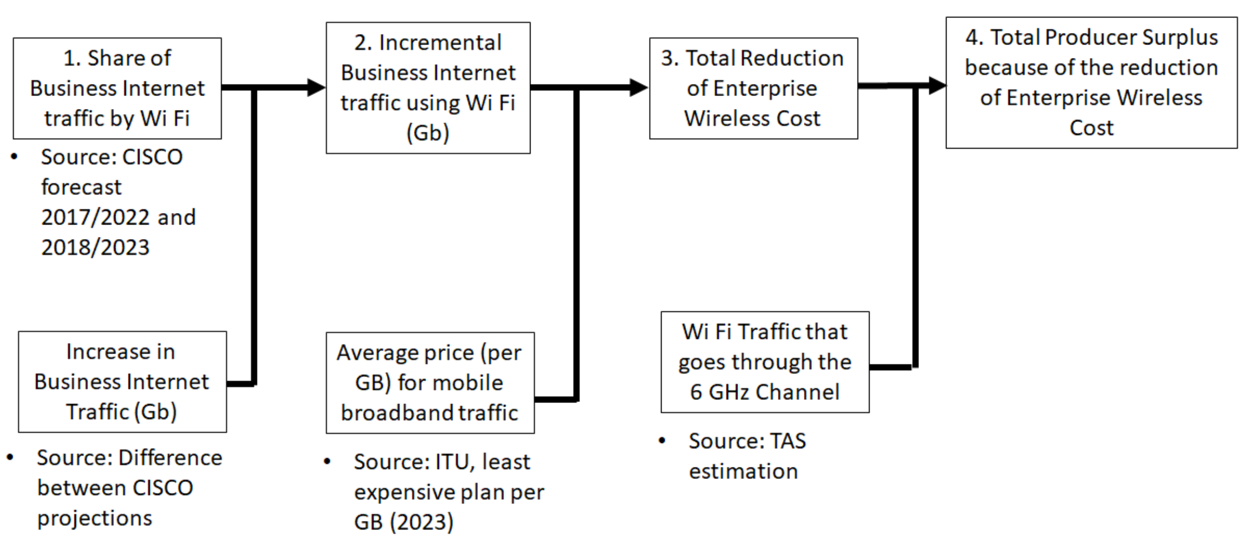
According to the data in line 13, cumulative impact of enhanced IoT deployment driven by 6 GHz spectrum total allocation for restricted radiation equipment use will reach US$47.69 billion between 2024 and 2034.

2.2.4. Reduction of enterprise wireless costs

The deployment of the enterprise applications based on IoT and AR/VR (which is analyzed below) among other use cases will generate an exponential growth in data traffic that will be handled by devices operating in restricted radiation equipment spectrum, through the combination of the existing 2.4 GHz, the lower 5 GHz, and the 6 GHz band. Under current conditions, enterprise Wi-Fi networks run 20 or 40 MHz channels due to spectrum shortfall and device restrictions. Wi-Fi requires 80 MHz channels to offer 1 Gb of throughput, which provides an indication of existing constraints. Thus, 6 GHz allocation is critical to handle enterprise applications. The impact on GDP of having a suitable spectrum environment to run these applications has been addressed in the IoT and AR/VR chapters under the heading of spillovers.

The allocation of 6 GHz also has an economic effect in enterprise margins (or producer surplus), in terms of the savings from cellular usage implied by using restricted radiation equipment spectrum to handle traffic from high-capacity Wi-Fi devices rather than cellular networks. The methodology to assess this benefit proceeds by multiplying the average price per Gigabyte of wireless data transmitted by wideband networks, which we calculate by averaging the most economic "dollar per GB" (for the least expensive plans) plan of major wireless carriers in Brazil (see figure 2-7).

Figure 2-7. Methodology for estimating a reduction in enterprise wireless cost



Source: Telecom Advisory Services

In 2017, the Cisco VNI estimated that for 2023 total business Internet traffic would reach 12.60 billion GB. In 2018, an updated Cisco traffic forecast based on the explosion of IoT and

AR/VR applications, among other factors, increased total Internet traffic reaching 13.10 billion GB (see Table 2-23).

Table 2-23. Brazil: Enterprise Wireless Traffic ('000) (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Total Business Internet Traffic (Gb) Old Projection	14,010,424	15,571,589	17,306,713	19,235,180	21,378,534	23,760,719	26,408,348	29,351,000	32,621,548	36,256,529	40,296,551
(2) Total Business Internet Traffic (Gb) New Projection	14,927,419	17,011,950	19,387,574	22,094,941	25,180,376	28,696,676	32,704,007	37,270,940	42,475,619	48,407,103	55,166,886
(3) Incremental Business Internet Traffic	916,995	1,440,361	2,080,861	2,859,761	3,801,843	4,935,957	6,295,659	7,919,940	9,854,072	12,150,574	14,870,334

Source: Cisco Visual Networking Index (2017), (2018)

Each growth forecast was converted to dollar values based on the price per GB[28] (see Table 2-24).

Table 2-24. Brazil: Cost of Enterprise Internet Traffic (2024-2034) (IN US$)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(4) Average Price per Gb	$0.54	$0.49	$0.45	$0.41	$0.37	$0.35	$0.32	$0.30	$0.28	$0.27	$0.25
(5) Economic Impact (US$ Billion)	$ 0.499	$ 0.708	$ 0.929	$ 1.166	$ 1.423	$ 1.706	$ 2.020	$ 2.372	$ 2.769	$ 3.221	$ 3.738

Source: UIT; Telecom Advisory Services analysis

We assume that part of the traffic growth presented in table 2-24 will be driven by "natural" growth, while the remainder will be triggered by Wi-Fi traffic stimulated by changes in 6 GHz allocation (see Table 2-25).

Table 2-25. Brazil: Enterprise Wireless Traffic: Growth triggered by broader Wi-Fi traffic (2024-2034) (in '000'000 US$)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(6) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(7) Economic impact of 6 GHz Band (US$ Billion)	$ 0.150	$ 0.265	$ 0.418	$ 0.612	$ 0.854	$ 1.152	$ 1.515	$ 1.898	$ 2.354	$ 2.899	$ 3.551

Source: Telecom Advisory Services analysis

The sum of the difference due to broader Wi-Fi traffic between 2024 and 2034 will reach US$15.668 billion.

2.2.5. Deployment of AR/VR solutions

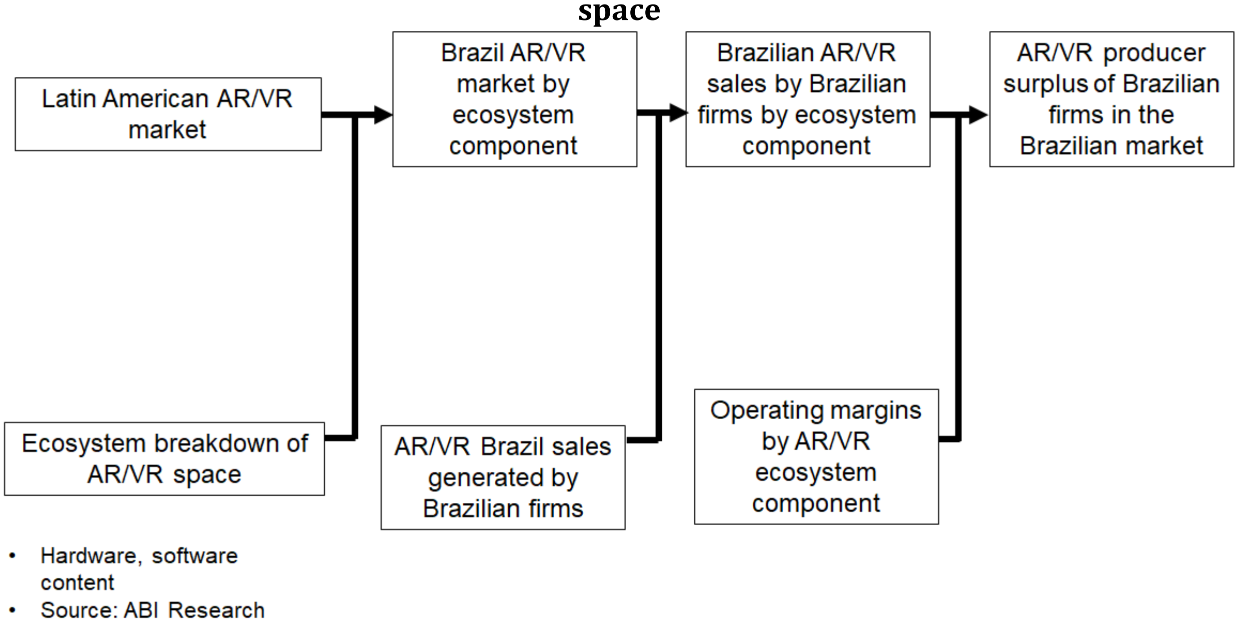
[28] According to the UIT, in 2023 the price for a 10 GB plan was $30 (US$ 6.06). When converted to price per GB, it resulted in US$ 0.61.

The AR/VR market in Brazil is estimated at US$ 854 million at 2023[29], of which US$ 223 million is hardware (such as smart and non-smart glasses), and US$ 630 million is software and applications (including systems integration, platform, and licensing). By 2034 the market will reach US$13.83 billion (US$2.32 billion hardware and US$11.51 billon software and applications)[30]. Sales by Brazilian firms to Brazilian businesses will generate producer surplus (i.e. margins), while the technology will yield spillovers in enterprise productivity.

2.2.5.1. Producer surplus derived from sale of Virtual Reality and Augmented Reality solutions

The development and diffusion of AR/VR applications in the production side of the economy is being driven by an ecosystem comprised of firms ranging from software development to hardware production and content creation. The key objective is to estimate the producer surplus generated in Brazil because of the sales of AR/VR applications produced by domestic firms (see Figure 2-8).

Figure 2-8. Methodology for estimating Brazilian producer surplus in the AR/VR space



Source: Telecom Advisory Services

Our starting point is the sales of AR/VR applications and systems within Brazil between 2024 and 2034 (one could potentially include exports to other countries, although we exclude this for conservative purposes). We estimate this by prorating Latin American projections for Brazil based on its GDP and break it down by ecosystem component according to ABI Research studies (see table 2-26).

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[29] Source: TAS Analysis based on ABI Research data for LATAM

[30] Data calculated based on Latin American totals as estimated by ABI Research.

Table 2-26. Brazil: AR/VR market by component (2024-2034) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	$ 0.38	$ 0.56	$ 0.80	$ 1.03	$ 1.21	$ 1.37	$ 1.52	$ 1.69	$ 1.88	$ 2.09	$ 2.32
Software & Applications	$ 0.98	$ 1.48	$ 2.09	$ 2.82	$ 3.43	$ 4.20	$ 5.14	$ 6.29	$ 7.69	$ 9.41	$ 11.51
TOTAL	$ 1.36	$ 2.05	$ 2.88	$ 3.84	$ 4.64	$ 5.57	$ 6.66	$ 7.98	$ 9.57	$ 11.50	$ 13.83

Source: ABI Research; Telecom Advisory Services analysis

Sales are broken down by two components of the ecosystem: hardware, and applications and software, but each component is restricted to the Brazilian firms, because the purpose is to estimate the value generated by the domestic producers (therefore, we exclude sales in Brazil generated by foreign firms). A key assumption in this regard is that Brazilian firms only supply 15% of the AR/VR hardware in 2023, although that share will increase over time reaching 50% by 2034. On the other hand, Brazilian firms are assumed to hold 55% for software and content market, reaching 90% in 2034. This recognizes that the development of this market should be accompanied by a concerted industrial policy aimed at developing local firms in these two components (see Table 2-27).

Table 2-27. Brazil: AR/VR sales by Brazilian firms by component (2020-2030) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	$ 0.08	$ 0.14	$ 0.24	$ 0.36	$ 0.48	$ 0.61	$ 0.76	$ 0.84	$ 0.94	$ 1.05	$ 1.16
Software & Applications	$ 0.59	$ 0.96	$ 1.46	$ 2.11	$ 2.74	$ 3.57	$ 4.63	$ 5.66	$ 6.92	$ 8.47	$ 10.36
TOTAL	$ 0.67	$ 1.10	$ 1.70	$ 2.47	$ 3.23	$ 4.19	$ 5.39	$ 6.51	$ 7.86	$ 9.51	$ 11.52

Source: ABI Research; Telecom Advisory Services analysis

A portion of this surplus is not due exclusively to the designation of Very Low Power devices within the 6 GHz band. The development of AR/VR has already begun before this potential spectrum change. In the absence of any precise metric, we applied the ratio used to determine the impact on AR/VR market growth ranging between 22.11% of sales in 2024 and 77.25% in 2034 (see Table 2-28).

Table 2-28. Brazil: AR/VR sales by Brazilian firms attributed to the designation of Very Low Power devices within the 6GHz band (2024-2034) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Due to 6 GHz (%)	22.11%	27.95%	34.46%	42.58%	51.28%	59.81%	66.81%	71.47%	74.58%	76.45%	77.25%
Due to 6 GHz (US$ B)	$ 0.15	$ 0.31	$ 0.59	$ 1.05	$ 1.65	$ 2.50	$ 3.60	$ 4.65	$ 5.86	$ 7.27	$ 8.90

Source: ABI Research; Telecom Advisory Services analysis.

Once sales by Brazilian firms in the Brazilian market in the 6 GHz are calculated, producer surplus for the AR/VR Brazilian industry is estimated based on standard margin metrics: 39.44% for hardware, and 77.46% for software and content (see Table 2-29).

Table 2-29. Brazil: Producer surplus derived from AR/VR sales by Brazilian firms by component (2024-2034) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hardware	$ 0.01	$ 0.02	$ 0.03	$ 0.06	$ 0.10	$ 0.14	$ 0.20	$ 0.24	$ 0.28	$ 0.32	$ 0.35
Software & Applications	$ 0.10	$ 0.21	$ 0.39	$ 0.70	$ 1.09	$ 1.66	$ 2.39	$ 3.13	$ 4.00	$ 5.01	$ 6.20
TOTAL	$ 0.11	$ 0.22	$ 0.42	$ 0.76	$ 1.19	$ 1.80	$ 2.60	$ 3.37	$ 4.28	$ 5.33	$ 6.55

Source: CSI Market Inc*: Industry Profitability ratios; ABI Research; Telecom Advisory Services analysis*

In sum, the total producer surplus value of AR/VR in Brazil (the direct impact) between 2024 and 2034 is US$26.62 billion.

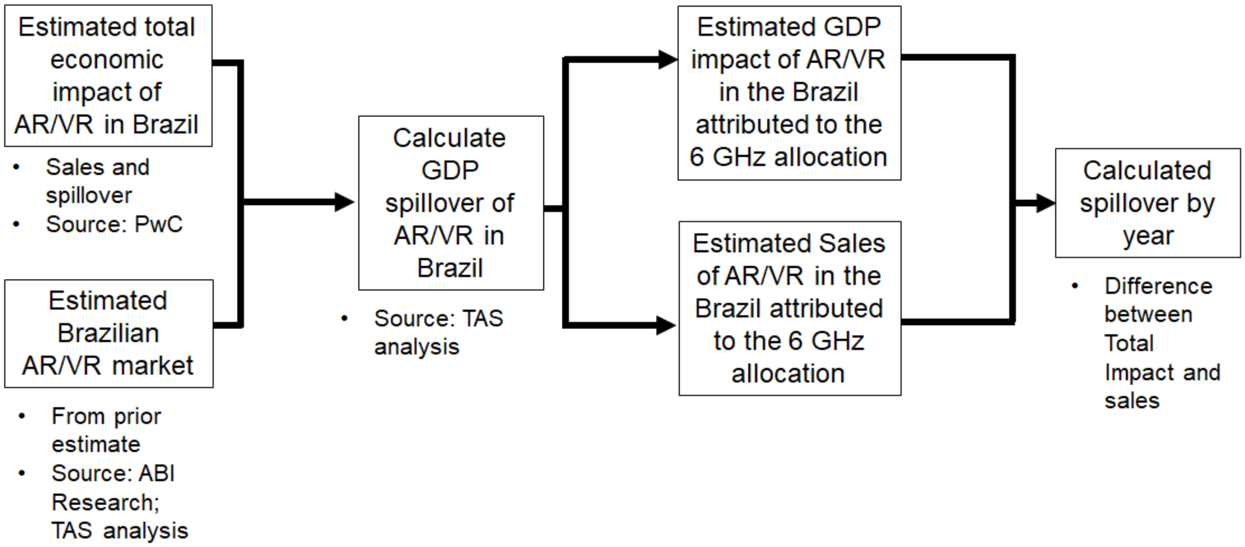
2.2.5.2. Spillovers from Virtual Reality (VR) and Augmented Reality (AR)

The adoption of AR/VR among Brazilian businesses will, in turn, have a spillover effect on productivity, thereby contributing to the growth of GDP. The spillover effects range from improved training to the acceleration of product design and delivery. For example, automotive companies are already incorporating VR in their product development processes to reduce the time incurred between initial design and physical modelling. AR glasses also help warehouse workers provide parts information for engineers and technicians in the field. Finally, AR/VR solutions can be used to sell and showcase products in retailing.

Because the objective is to estimate the spillover effect of AR/VR sales by Brazilian firms in the domestic market resulting from the growth driven by designating VLP devices as part of the 6 GHz band, our point of departure is the total GDP contribution of AR/VR, as estimated by PwC that indicates the weight of AR/VR in the GDP by region[31], and the sales of AR/VR components as derived from ABI Research data. These two parameters allow estimating the indirect (that is to say spillover) contribution of AR/VR to the Brazilian economy (see Figure 2-9).

[31] PWC (2019). *Seeing is believing: how virtual reality and augmented reality are transforming business and the economy.*

Figure 2-9. Methodology for estimating AR/VR spillovers



Source: Telecom Advisory Services

Both starting values are downward-adjusted by the proportion that can be attributed to the impact of the 6 GHz spectrum allocation of VLP devices (in other words, it would be wrong to estimate that the whole economic value of the AR/VR is driven by the spectrum changes). Once the amount to be attributed in both GDP contribution and direct sales is estimated, the GDP contribution is quantified (see Table 2-30).

Table 2-30. Brazil: GDP Contribution resulting from AR/VR Spillovers (2024-2034) (in US$ billion)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
AR/VR Boost to GDP (% GDP)	0.31%	0.38%	0.46%	0.56%	0.70%	0.89%	1.12%	1.34%	1.55%	1.70%	1.79%
Brazil GDP (US$ Billions)	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
AR/VR Boost to GDP (US$ Millions)	$ 7,022	$ 8,976	$ 11,392	$ 14,740	$ 19,421	$ 26,027	$ 34,523	$ 43,667	$ 52,931	$ 61,371	$ 67,922
AR/VR Boost to GDP without 6.0 GHz Band (US$ Millions)	$ 5,469	$ 6,468	$ 7,466	$ 8,464	$ 9,463	$ 10,461	$ 11,460	$ 12,458	$ 13,456	$ 14,455	$ 15,453
AR/VR Boost to GDP due to 6.0 GHz Band (US$ Millions)	$ 1,552	$ 2,508	$ 3,926	$ 6,276	$ 9,958	$ 15,566	$ 23,064	$ 31,209	$ 39,475	$ 46,916	$ 52,469
Direct impact	$ 0.30	$ 0.57	$ 0.99	$ 1.64	$ 2.38	$ 3.33	$ 4.45	$ 5.70	$ 7.14	$ 8.79	$ 10.69
Indirect impact	$ 1.25	$ 1.94	$ 2.93	$ 4.64	$ 7.58	$ 12.23	$ 18.61	$ 25.51	$ 32.34	$ 38.13	$ 41.78

Source: ABI Research; CSI Market Inc *: Industry Profitability ratios; Telecom Advisory Services analysis.*

Total spillover value of AR/VR in Brazil (the indirect impact) between 2024 and 2034 is US$186.94 billion.

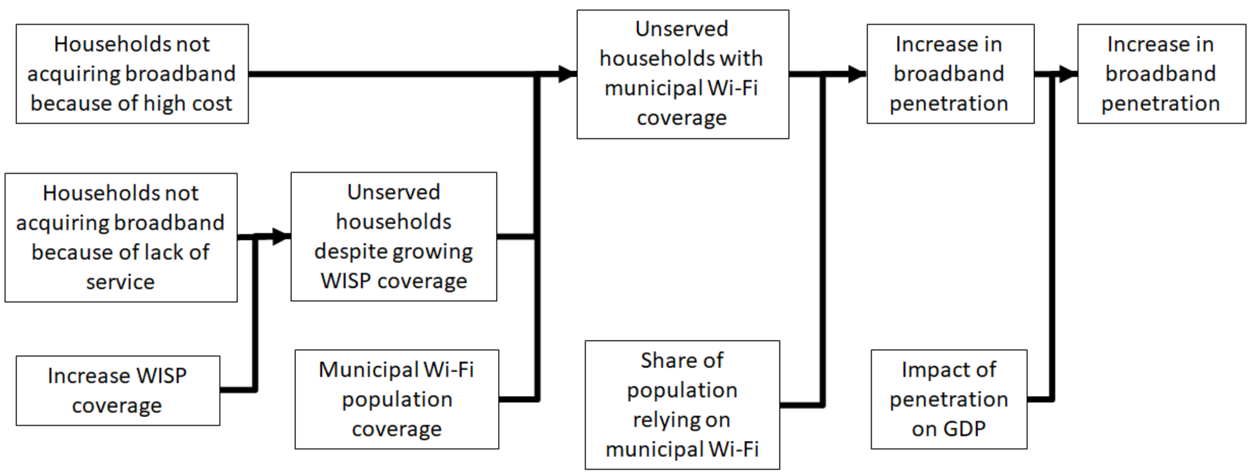
2.2.6. Enhanced deployment of municipal Wi-Fi

It has been reported that 3,230 (or 57.99 %) Brazilian municipalities already offer free Wi-Fi service relying on 20,730 Wi-Fi points[32]. This infrastructure can play a role in enhancing broadband service coverage by providing a free resource for consumers to gain access to the Internet. Along these lines, allocating spectrum in the 6 GHz band will increase the ability of municipal Wi-Fi to provide free service to unserved population or increase the speed of access for current users. These two effects translate into a contribution to GDP and an increase in consumer surplus.

2.2.6.1. Impact of enhanced Municipal Wi-Fi on GDP

The municipal Wi-Fi sites that incorporate technology relying on 6 GHz spectrum will be able to handle a larger number of users than under the current spectrum conditions which will, in turn, have an impact on the GDP. The methodology to estimate this effect is presented in figure 2-10.

Figure 2-10. Methodology for estimating GDP impact of Municipal Wi-Fi



Source: Telecom Advisory Services

The universe for assessing the impact of municipal Wi-Fi is the urban environment, where 80% of the Brazilian population resides. According to the Cetic.br survey of 2023, 573,572 do not access internet for lack of service coverage. In order to determine the universe benefitting from municipal broadband, we discounted from the household's lacking coverage, the increased deployment of WISPs, potential providers. By 2024, the first year of impact of this last variable, the number of benefitting households reaches 343,483. As a result, the number of "digital divide" households is 3,229,781, declining to 2,819,713 by 2034 (see table 2-31).

[32] Ministerio das Comunicacoes - https://www.gov.br/mcom/pt-br/acesso-a-informacao/acoes-e-programas/programas-projetos-acoes-obras-e-atividades/wi-fi-brasil

Table 2-31. Brazil: "Digital Divide" households ('000)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Households that do not buy because affordability	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
(2) Households that don´t buy because lack of coverage at their homes	574	574	574	574	574	574	574	574	574	574	574
(3) Households that now are serve by WISP	343	414	479	538	593	643	688	708	725	740	754
(4) Digital divide households	3,230	3,160	3,095	3,035	2,981	2,931	2,885	2,865	2,848	2,833	2,820

Source: CeTic.Br; ANATEL; Telecom Advisory Services analysis.

Accordingly, by 2023 57.99% of all Brazilian municipalities had deployed municipal Wi-Fi networks. However, the number of municipalities that have deployed municipal Wi-Fi is expected to increase over time, reaching 93% by 2034. Beyond this trend, we need to isolate the number of households that would benefit from municipal Wi-Fi networks being able to rely on 6 GHz spectrum. This resource would allow municipal networks to serve a larger number of users than under current restricted radiation equipment spectrum allocation. Furthermore, it is expected that not all unserved households would rely on municipal Wi-Fi due to geographic reasons, time availability and the like. Along these lines, we assume that, conservatively, only 10% of unserved households would use the municipal service (see table 2-32).

Table 2-32. Brazil: Households benefitting from Municipal Wi-Fi Networks with 6 GHz spectrum

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(4) Digital divide households	3,229,781	3,159,502	3,094,750	3,035,202	2,980,554	2,930,515	2,884,813	2,865,312	2,848,055	2,832,900	2,819,713
(5) Municipal Wi-Fi deployment (% Total Municipalities)	60.54%	63.20%	65.98%	68.88%	71.90%	75.07%	78.37%	81.81%	85.41%	89.16%	93.08%
(6) Share of the population that have access to a Wi-Fi Municipal point	60.54%	63.20%	65.98%	68.88%	71.90%	75.07%	78.37%	81.81%	85.41%	89.16%	93.08%
(7) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(8) New households that now can have broadband	355,102	473,231	606,214	755,961	924,624	1,114,626	1,328,693	1,534,165	1,765,801	2,026,808	2,320,769
(9) Share of population that effectively goes to a Municipal Wi-Fi Point	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
(10) Number of households relying on municipal Wi-Fi	35,510	47,323	60,621	75,596	92,462	111,463	132,869	153,416	176,580	202,681	232,077

Source: Telecom Advisory Services analysis.

The number of households that will be able to benefit from municipal Wi-Fi networks gaining access to 6 GHz spectrum represents an increase in the total of Brazilian served households.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP[33] yields the total GDP impact (see table 2-32).

Table 2-32. Brazil: GDP impact of Municipal Wi-Fi networks with 6 GHz spectrum

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(10) Number of households relying on municipal Wi-Fi	35,510	47,323	60,621	75,596	92,462	111,463	132,869	153,416	176,580	202,681	232,077
(11) Households with Fixed Broadband (000'000)	50.144	53.024	55.821	58.336	58.619	58.891	59.163	59.437	59.713	59.989	60.267
(12) Increase in national broadband penetration	0.07%	0.09%	0.11%	0.13%	0.16%	0.19%	0.22%	0.26%	0.30%	0.34%	0.39%
(13) Impact of fixed broadband adoption in GDP	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492
(14) Increase in the GDP due to the new broadband adoption (% GDP)	0.01%	0.01%	0.02%	0.02%	0.02%	0.03%	0.03%	0.04%	0.04%	0.05%	0.06%
(15) GDP (US$ Billion)	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
(16) Total impact in GDP (US$ Billion)	$ 0.239	$ 0.315	$ 0.401	$ 0.509	$ 0.653	$ 0.826	$ 1.033	$ 1.251	$ 1.511	$ 1.820	$ 2.186

Source: IMF; ITU; Telecom Advisory Services analysis.

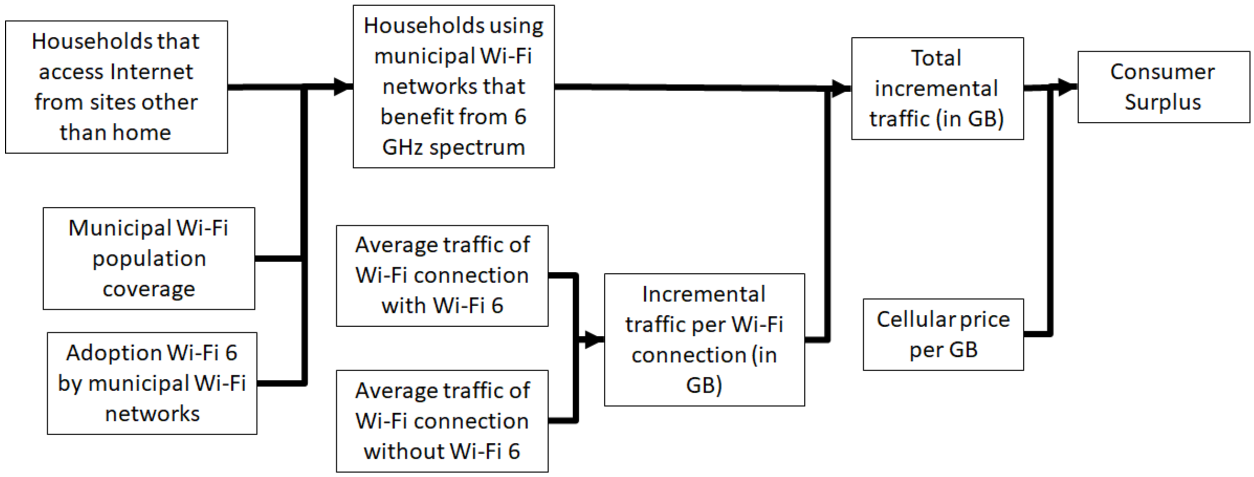
In sum, the cumulative contribution of GDP of the benefit accorded to municipal Wi-Fi networks by allocating spectrum in the 6 GHz band will reach US$10.744 billion between 2024 and 2034.

2.2.6.2. Contribution of enhanced Municipal Wi-Fi on consumer surplus

In addition to the contribution to GDP, municipal Wi-Fi networks with the capacity to leverage spectrum in 6 GHz can enhance their performance, providing faster broadband service, and thereby generating incremental consumer surplus (see Figure 2-11).

[33] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

Figure 2-11. Methodology for estimating consumer surplus of Municipal Wi-Fi



Source: Telecom Advisory Services analysis

The purpose of this analysis is to estimate the difference in the download speed of municipal Wi-Fi service before and after the allocation of 6 GHz spectrum for those households that do not purchase broadband service and are compelled to rely on this service to gain Internet access. We start by relying on Cetic.br survey data indicating those households that access the Internet from sites away from home (e.g. work, place of study, free sites, and municipal Wi-Fi): 1,036,975 at 2023. Of this universe, not all households have the capability of relying on municipal Wi-Fi because not all municipalities have deployed networks (as mentioned above, only 57.99% have done so). Because the objective is to estimate the incremental impact of 6 GHz, we factor the population coverage by Wi-Fi 6 adoption in municipal Wi-Fi networks, which is assumed to grow from 30% in 2024 to 95% in 2034. This yields the population that accesses the Internet away from home who benefit from municipal Wi-Fi that has adopted Wi-Fi 6: it starts at 114,011 in 2024 and increases to 853,484 in 2034 (see table 2-33).

Table 2-33. Brazil: Households benefiting from municipal Wi-Fi that have adopted Wi-Fi 6

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Households that do not buy broadband service because have alternative access ('000)	1,037	1,037	1,037	1,037	1,037	1,037	1,037	1,037	1,037	1,037	1,037
(2) Municipal Wi Fi deployment (% Total Municipalities)	60.54%	63.20%	65.98%	68.88%	71.90%	75.07%	78.37%	81.81%	85.41%	89.16%	93.08%
(3) Share of the population that have access to a Wi Fi Municipal point	60.54%	63.20%	65.98%	68.88%	71.90%	75.07%	78.37%	81.81%	85.41%	89.16%	93.08%
(4) Municipal networks adopting Wi-Fi 6	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(5) Households covered by Wi-Fi Municipal with 6 GHz band	114,011	155,318	203,128	258,274	321,689	394,415	477,612	555,224	642,927	741,907	853,484

Source: Cetic.Br; Ministerio das Comunicacoes; Telecom Advisory Services analysis.

These households will benefit from the incremental traffic generated under Wi-Fi 6. To estimate this, we assume that current traffic per line stays at current level, while under Wi-Fi 6 it will grow as projected by CISCO VNI. The difference is multiplied by the price per GB in Brazil as reported by the ITU for Brazil (see table 2-34).

Table 2-34. Brazil: Consumer surplus of households benefitting from municipal Wi-Fi in networks that have adopted Wi-Fi 6

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(6) Traffic after speed increase (Gb)	36.58	42.50	49.38	57.38	66.66	77.45	89.99	104.55	121.48	141.14	163.98
(7) Traffic with speed without 6 GHz (Gb)	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08
(8) Yearly Increase in traffic (Billions of Gb)	0.021	0.039	0.067	0.108	0.167	0.253	0.373	0.524	0.729	1.004	1.373
(9) Price per Gb	$ 0.54	$ 0.49	$ 0.45	$ 0.41	$ 0.37	$ 0.35	$ 0.32	$ 0.30	$ 0.28	$ 0.27	$ 0.25
(10) Total impact in consumer surplus (US$ Billion)	$ 0.011	$ 0.019	$ 0.030	$ 0.044	$ 0.063	$ 0.087	$ 0.120	$ 0.157	$ 0.205	$ 0.266	$ 0.345

Source: CISCO VNI; UIT; Telecom Advisory Services analysis.

The cumulative consumer surplus to be generated by this effect amounts to US$1,347 million between 2024 and 2034.

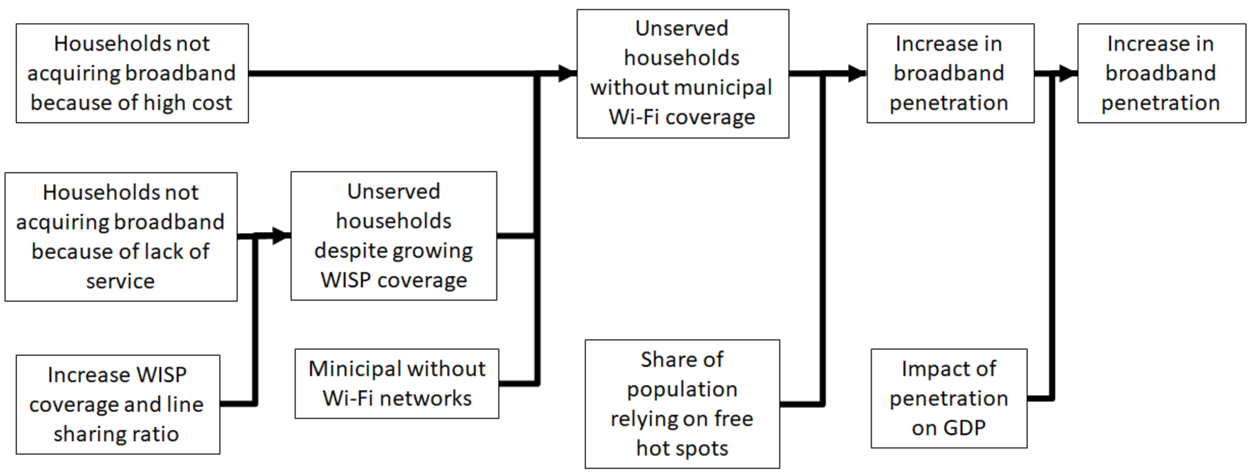
2.2.7. Deployment of Free Wi-Fi Hot Spots

The assessment of economic impact of the 6 GHz allocation in the case of free hot spots is similar to the one conducted for municipal Wi-Fi networks. The underlying assumption in this case is that free Wi-Fi hot spots that benefit from 6 GHz spectrum will be capable of handling a higher number of devices, which in turn will contribute to broadband adoption. On the other hand, these sites will be able to deliver faster speed of service, which can be transferred to increasing consumer well-being.

2.1.7.1. Impact of enhanced free Wi-Fi hot spots on GDP

As in the case of municipal Wi-Fi networks, the free hot spot sites that incorporate technology relying on 6 GHz spectrum will be able to handle a larger number of users than under the current spectrum conditions which would in turn have an impact on the GDP. The methodology to quantify this effect is presented in figure 2-12.

Figure 2-12. Methodology for estimating GDP impact of Municipal Wi-Fi



Source: Telecom Advisory Services

Our starting point is the households that lack broadband access at home due to limited affordability and that do not have the benefit of relying on municipal Wi-Fi. We subtract from this universe, those households that will be served by WISPs in the future, so as not to incur in double counting. From this group, we estimate those that could be served by free sites having implemented Wi-Fi 6 and assume that only 5% of them will effectively rely on a free site to gain Internet access. This is the incremental broadband penetration that is used to quantify the impact on GDP by relying on the same coefficient as the one used in the case of municipal Wi-Fi (see table 2-35).

Table 2-35. Brazil: GDP impact of Free Wi-Fi hot spots with 6 GHz spectrum

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Households that do not purchase broadband because affordability barrier ('000)	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
(2) Households that do not purchase broadband due to lack of coverage in urban areas ('000)	574	574	574	574	574	574	574	574	574	574	574
(3) Households that are served by WISPs	343,483	413,762	478,514	538,062	592,710	642,749	688,451	707,952	725,209	740,364	753,551
(4) Potential Free Wi-Fi coverage (households) ('000)	3,230	3,160	3,095	3,035	2,981	2,931	2,885	2,865	2,848	2,833	2,820
(5) Households that have access to Municipal Wi-Fi	355,102	473,231	606,214	755,961	924,624	1,114,626	1,328,693	1,534,165	1,765,801	2,026,808	2,320,769
(6) Potential Free Wi Fi market ('000)	2,875	2,686	2,489	2,279	2,056	1,816	1,556	1,331	1,082	806	499
(7) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(8) New households that now can have broadband ('000)	862	1,007	1,120	1,197	1,234	1,226	1,167	1,065	920	725	474
(9) Urban Share of households	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%	74.71%
(10) Share of population that effectively goes to a Free Wi Fi Spot	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
(11) Households with Fixed Broadband ('000)	50,144	53,024	55,821	58,336	58,619	58,891	59,163	59,437	59,713	59,989	60,267
(12) Increase in national broadband penetration	0.06%	0.07%	0.07%	0.08%	0.08%	0.08%	0.07%	0.07%	0.06%	0.05%	0.03%
(13) Impact of fixed broadband adoption in GDP	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492	0.1492
(14) Increase in the GDP due to the new broadband adoption (% GDP)	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%
(15) GDP (US$ Billion)	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
(16) Total impact in GDP (US$ Billion)	$ 0.217	$ 0.250	$ 0.277	$ 0.301	$ 0.325	$ 0.339	$ 0.339	$ 0.324	$ 0.294	$ 0.243	$ 0.167

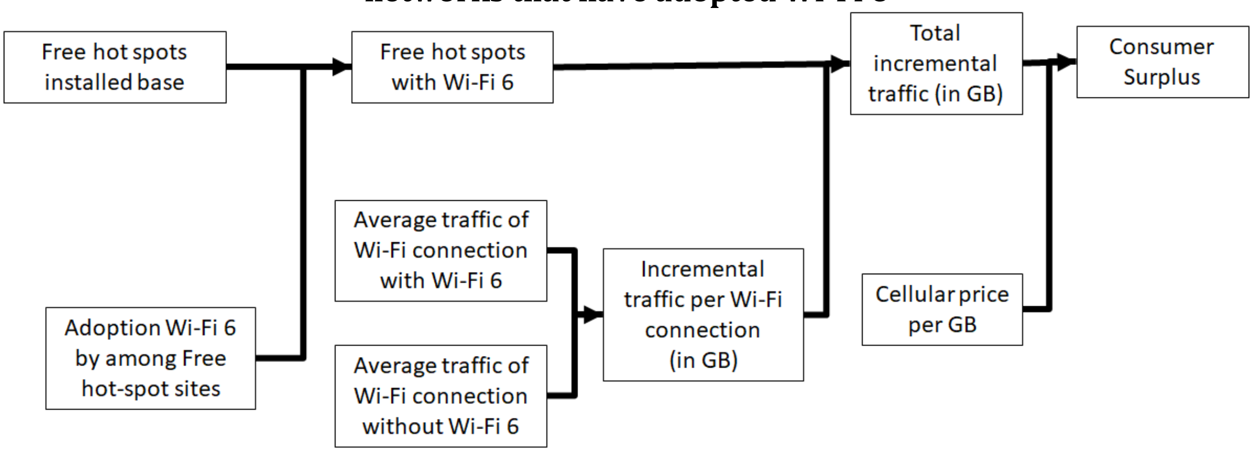
Source: Cetic.Br; Ministerio das Comunicacoes; UIT; IMF; ITU; Telecom Advisory Services analysis.

The cumulative GDP contribution to be generated by this effect amounts to US$3,077 million between 2024 and 2034.

2.2.7.2. Impact of enhanced free Wi-Fi hot spots on consumer surplus

The adoption of Wi-Fi 6 technology across free Wi-Fi hot spots will render them capable of delivering faster throughput (like the case of municipal Wi-Fi networks). By applying the price per GB for the incremental traffic to be conducted through the free sites, we estimate the consumer surplus (see figure 2-13).

Figure 2-13. Brazil: Consumer surplus of users benefitting from free Wi-Fi in networks that have adopted Wi-Fi 6



Source: Telecom Advisory Services

Assuming the same Wi-Fi 6 adoption among free hot spots, the incremental traffic generated under Wi-Fi 6 is quantified. To estimate this, we assume that current traffic per line stays at the current levels, while under Wi-Fi 6 it will grow as projected by CISCO VNI. The difference is multiplied by the price per GB in Brazil as reported by the ITU (see table 2-36).

Table 2-36. Brazil: Consumer surplus of households benefitting from free Wi-Fi in networks that have adopted Wi-Fi 6

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Free hotspots (‘000)	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147
(2) Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(3) Hotspots using the 6 GHz Band (‘000)	344	430	516	602	688	774	860	917	975	1,032	1,089
(4) Traffic after speed increase (Gb)	36.58	42.50	49.38	57.38	66.66	77.45	89.99	104.55	121.48	141.14	163.98
(5) Traffic with speed without 6 GHz (Gb)	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08
(6) Yearly Increase in traffic (Billions of Gb)	0.063	0.108	0.169	0.251	0.358	0.496	0.672	0.866	1.105	1.396	1.752
(7) Price per Gb	$ 0.54	$ 0.49	$ 0.45	$ 0.41	$ 0.37	$ 0.35	$ 0.32	$ 0.30	$ 0.28	$ 0.27	$ 0.25
(8) Total impact in consumer surplus (US$ Billion)	$ 0.035	$ 0.053	$ 0.075	$ 0.102	$ 0.134	$ 0.172	$ 0.216	$ 0.259	$ 0.310	$ 0.370	$ 0.440

Source: Wi-Fi Map; CISCO VNI; ITU; Telecom Advisory Services analysis.

The cumulative consumer surplus to be generated by this effect amounts to US$2,167 million between 2024 and 2034

2.2.8. Aligning spectrum decision with other advanced economies

By allocating spectrum in the 6 GHz band, Brazil will not only alleviate the pressure on restricted radiation equipment spectrum resulting from explosive Wi-Fi usage but will also have implications for the cost of inputs for Brazilian firms and for the country's industrial policy. If Brazil was to align itself with the United States and Korean 6 GHz allocation model, it would benefit from acquiring equipment whose average selling price would be lower than the equipment used in the European one. Our comparison of unit prices of AR monocular glasses indicates a persistent advantage of the US model relative to the European model (see table 2-37).

Table 2-37. United States versus Europe: Average Selling Price of Monocular glasses

	2019	2020	2021	2022	2023	2024
United States	761.16	709.14	656.94	606.29	564.49	528.85
Europe	766.25	715.60	665.82	617.24	574.03	537.53
Percent difference	-0.66%	-0.90%	-1.33%	-1.77%	-1.66%	-1.61%

Source: ABI Research 2020-2024; Telecom Advisory Services analysis

By extrapolating the trend through 2034 and applying the price difference to the AR/VR hardware and IoT hardware market, the following effect can be quantified (see table 2-38).

Table 2-38. Advantage of aligning the 6 GHz decision with the US model (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) AR-VR hardware market	$ 0.382	$ 0.562	$ 0.799	$ 1.028	$ 1.208	$ 1.366	$ 1.519	$ 1.690	$ 1.879	$ 2.090	$ 2.324
(2) IoT Hardware Market	$ 3.189	$ 3.504	$ 3.888	$ 4.111	$ 4.348	$ 4.306	$ 4.194	$ 4.061	$ 3.909	$ 3.744	$ 3.568
(3) Price reduction due to aligning spectrum decision	-1.61%	-1.54%	-1.47%	-1.40%	-1.34%	-1.28%	-1.22%	-1.16%	-1.10%	-1.04%	-0.98%
(4) Impact on producer surplus (US$B)	$ 0.058	$ 0.063	$ 0.069	$ 0.072	$ 0.074	$ 0.072	$ 0.070	$ 0.067	$ 0.064	$ 0.061	$ 0.058

Source: Telecom Advisory Services analysis based on ABI Research and Statista Market Insights

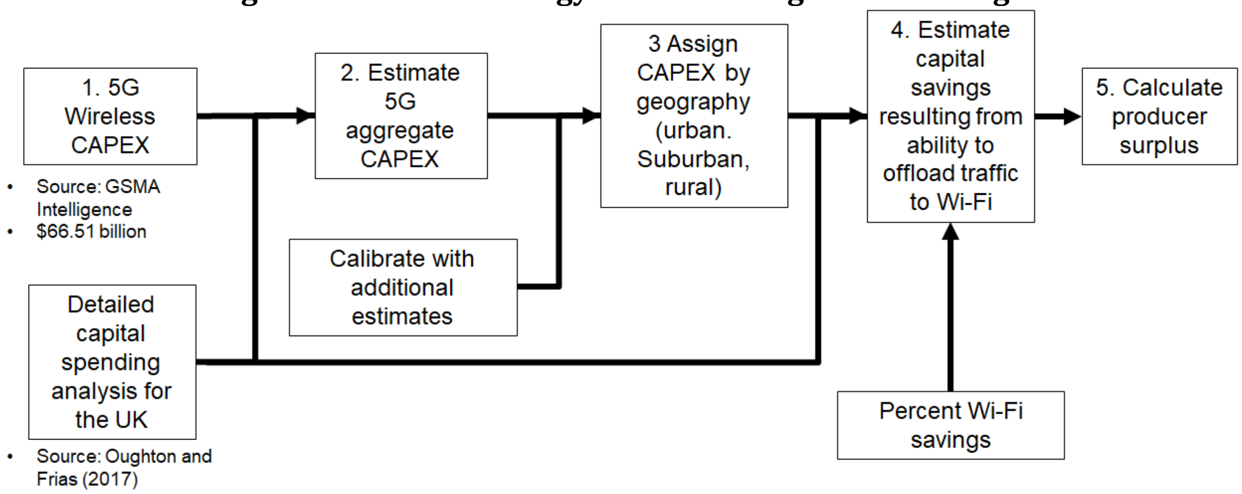
Under such an attractive demand condition, the decisions to be made in terms of the model of allocating the 6 GHz spectrum (European or US-Korean model) could put Brazil on the path to both meet the needs to local demand and benefitting from the implicit economies of scale derived from advanced markets as well as to increase the opportunity costs of those markets developing first. Additionally, the decision of aligning with a particular model could potentially give Brazil the benefit of developing an export-led industry that could capitalize on foreign demand.

2.2.9. Enhancing the capability for cellular off-loading

5G networks promise faster speeds, lower latency, and greater capacity to mobile users. However, 5G network operators cannot deliver on that promise without robust Wi-Fi networks to carry the majority of that traffic.

The key objective is to estimate the savings in capital investment as a result of an increase in traffic offloading with Wi-Fi benefits from the additional spectrum in the 6 GHz band, but more importantly, the ability to leverage 160 MHz within a single contiguous channel (see Figure 2-14).

Figure 2-14. Methodology for estimating CAPEX savings



Source: Telecom Advisory Services analysis

The analysis starts with an estimate of 5G deployment costs, absent the Wi-Fi offloading benefit. One approach (Step 1) is to sum wireless CAPEX estimated by GSMA Intelligence for Brazil between 2019 and 2034: US$66.51 billion. As an alternative approach, we rely on the only known rigorous cost estimation of 5G deployment to date: the one developed by Oughton and Frias (2017) for OFCOM in the United Kingdom. The authors' baseline case estimates a CAPEX of US$53.34 million, of which urban coverage investment amounts only to $890 million, while suburban deployment demands US$7.13 billion, and rural coverage US$45.32 billion (see Table 2-39).

Table 2-39. United Kingdom: 5G Investment

	Town/City (Million)	Population distribution	5G CAPEX ($ billion)	5G CAPEX (%)	CAPEX per POP
Urban (cities >1 million)	19.42	29%	$0.89	1.66%	$45.71
Suburban	36.16	54%	$7.13	13.37%	$197.16
Rural	11.38	17%	$45.32	84.97%	$3,981.22
Total	66.96	100%	$53.34	100%	$796.58

Source: Oughton and Frias (2017). Exploring the cost, coverage and rollout implications of 5G in Britain; Telecom Advisory Services analysis

Using capital investment per POP as a starting point (which does not include spectrum acquisition costs), deployment costs for networks aimed at providing 5G services in Brazil are calculated (Step 2).

Table 2-40. Brazil: 5G Investment

	Population (million)	Population distribution	5G CAPEX ($ billion)	5G CAPEX (%)	CAPEX per POP	Savings due to 6 GHZ ($ billion)
Urban (cities>1 million)	84.77	41%	$ 1.85	2.78%	$45.71	$ 0.00
Suburban	95.23	46%	$ 8.97	13.48%	$197.16	$ 1.34
Rural	29.30	14%	$ 55.70	83.74%	$3,981.22	$ 2.78
Total	209.30	100%	$ 66.51	100%	$442.02	$ 4.13

Source: Oughton and Frias (2017). Exploring the cost, coverage and rollout implications of 5G in Britain; Telecom Advisory Services analysis

Considering the cost decomposition of Oughton and Frias (2016), as well as that of the other estimates, the 5G investment under an exclusive licensed spectrum framework will remain significant for suburban (US$8.97 billion) and rural (US$55.70 billion) areas. In this context, restricted radiation equipment spectrum becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards, and short-range wireless technologies operating in restricted radiation equipment bands. A comparative analysis of CAPEX for 5G base station of pico cell vs. carrier grade Wi-Fi hotspot indicates a cost advantage of the latter amounting to 81%[34]. It should be noted that the Wi-Fi advantage in hybrid networks becomes even more relevant with the 6 GHz spectrum given the hot-spot capacity to handle large volumes of traffic.

We conservatively assume that Wi-Fi will not be critical in sustaining investment in urban areas, but that it will play a significant role in suburban and rural geographies. Based on the cost advantage of carrier grade Wi-Fi, we assume that it will become effective for a portion of the suburban (approximately 15%) and rural network (approximately 5%) deployment. Therefore, using the estimation of $8.97 billion for suburban coverage and US$55.70 billion for rural coverage, the implementation of Wi-Fi hotspots leveraging 6 GHz will yield CAPEX savings of US$ 4.13 billion between 2021 and 2034, that reach an annual impact of US$ 295 million (with the total value between 2024 and 2034 of US$ 3.24 billion). These will be critical in terms of allowing carriers to extend their 5G coverage further into rural geographies.

2.2.10. Wi-Fi Devices and equipment

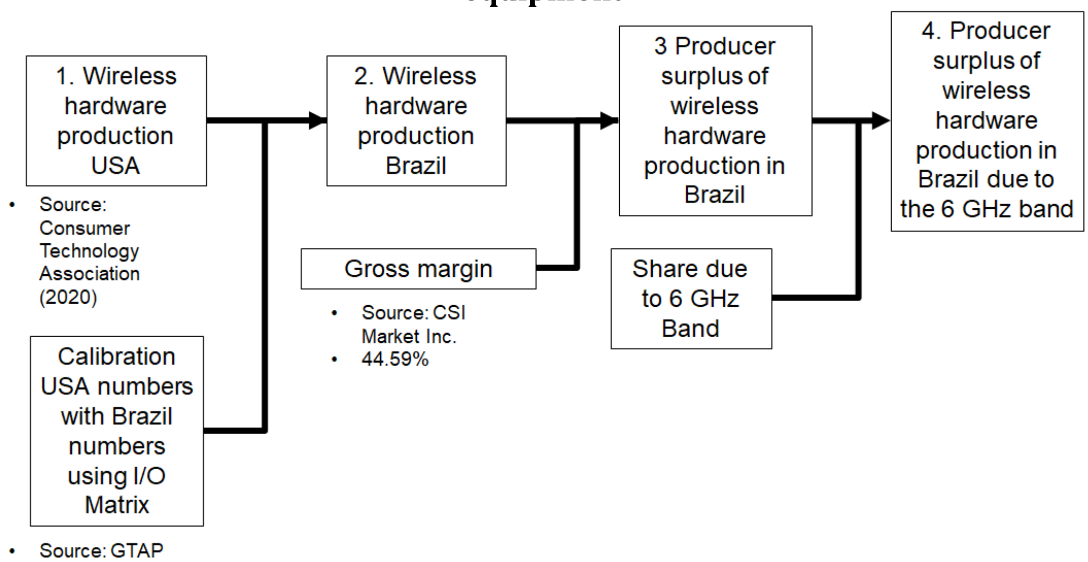
To estimate the producer surplus from Wi-Fi device and equipment sales in Brazil, the first step in the methodology requires the utilization of the Input-Output (I/O) Matrix to translate the wireless hardware production data from the United States to the Brazilian context. This

[34] Nikolikj, V. and Janevski, T. (2014). "A Cost Modeling of High-Capacity LTE-Advanced and IEEE 802.11ac based Heterogeneous Networks, Deployed in the 700 MHz, 2.6 GHz and 5 GHz Bands," *Procedia Computer Science* 40 (2014) 49-56.

transformation adjusts for differences in the countries' production capabilities, technological advancement, and other economic factors. The I/O Matrix acts as a calibrator, ensuring the American production data is reflective of Brazilian economic conditions, thereby establishing a baseline for the Brazilian production figures.

Once the production figures are contextualized for Brazil using the I/O Matrix, the next phase is to consider only the gross margin of the total revenue. To achieve this, it is essential to compute the gross margins for Wi-Fi devices and equipment's in Brazil, which are indicative of the profitability per unit. Subsequently, the surplus attributable to the 6 GHz band is isolated by analyzing the incremental market share and revenue resulting from the band's utilization (see figure 2-15).

Figure 2-15. Methodology for estimating producer surplus from Wi-Fi devices and equipment



Source: Telecom Advisory Services analysis

Utilizing the explained methodology, we estimate the producer surplus from Wi-Fi devices and equipment's in Brazil between 2024 and 2034 (see table 2-41).

Table 2-41. Producer surplus from Wi-Fi devices and equipment (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Wireless production (US$ million)	$3,706	$3,892	$4,086	$4,290	$4,505	$4,730	$4,967	$5,215	$5,476	$5,750	$6,037
Gross margin	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%
Producer surplus (US$ million)	$1,653	$1,735	$1,822	$1,913	$2,009	$2,109	$2,215	$2,325	$2,442	$2,564	$2,692
Share due to 6 GHz	22.39%	28.72%	34.42%	39.59%	44.28%	48.57%	52.51%	56.77%	61.37%	66.34%	71.72%
Producer surplus 6 GHz devices	$370	$498	$627	$757	$890	$1,025	$1,163	$1,320	$1,498	$1,701	$1,931

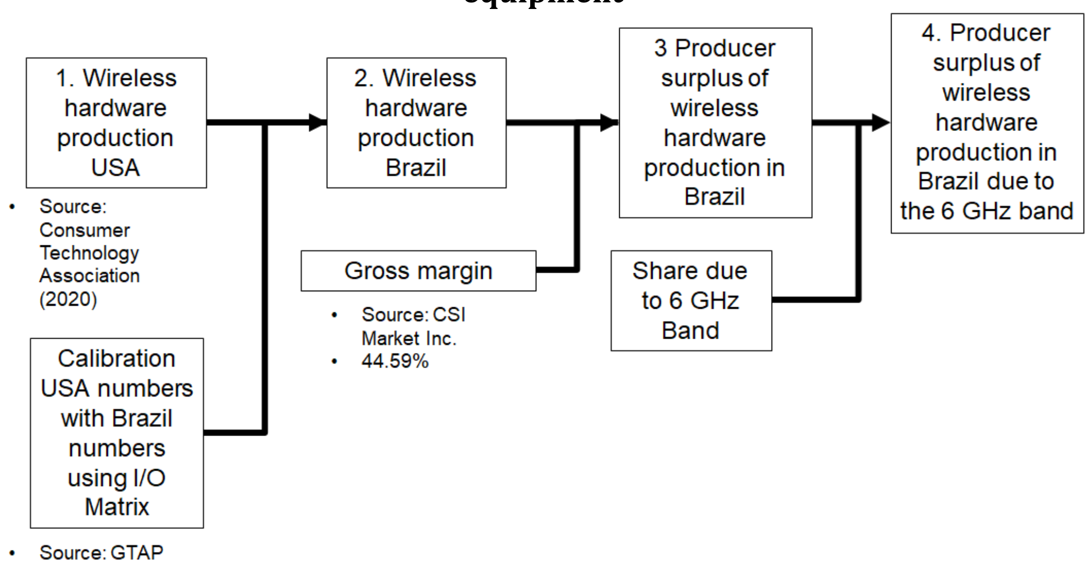
(US$ million)											

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative producer surplus to be generated by this effect amounts to US$11.78 billion between 2024 and 2034.

Apart from the producer surplus generated by Wi-Fi devices and equipment in Brazil, there is also the creation of a consumer surplus, which represents the difference between what consumers are willing to pay and what they actually spend. To estimate the consumer surplus for Brazil, one would take the revenue data from the United States as a starting point and then adjust it according to Brazil's GDP per capita. This adjustment accounts for the varying purchasing power between the two countries, acknowledging that the GDP per capita is a robust indicator of the general economic standing and consumer capacity. Unlike the previous calibration that employed an Input-Output Matrix to adjust for production capabilities, this method focuses on the economic ability of consumers to pay for Wi-Fi technology, thus enabling a tailored estimation of consumer benefits in the Brazilian market (see figure 2-16).

Figure 2-16. Methodology for estimating consumer surplus from Wi-Fi devices and equipment



Source: Telecom Advisory Services analysis

Utilizing the explained methodology, we estimate the consumer surplus from Wi-Fi devices and equipment's in Brazil between 2024 and 2034 (see table 2-42).

Table 2-42. Consumer surplus from Wi-Fi devices and equipment (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Wireless production (US$ million)	$7,852	$8,278	$8,758	$9,399	$10,001	$10,642	$11,323	$12,048	$12,820	$13,641	$14,514
Gross margin	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%	44.59%
Producer surplus (US$ million)	$3,501	$3,691	$3,905	$4,191	$4,459	$4,745	$5,049	$5,372	$5,716	$6,082	$6,472
Consumer surplus (US$ million)	$3,501	$3,691	$3,905	$4,191	$4,459	$4,745	$5,049	$5,372	$5,716	$6,082	$6,472
Share due to 6 GHz	22.39%	28.72%	34.42%	39.59%	44.28%	48.57%	52.51%	56.77%	61.37%	66.34%	71.72%
Consumer surplus 6 GHz devices (US$ million)	$784	$1,060	$1,344	$1,659	$1,975	$2,305	$2,651	$3,050	$3,508	$4,035	$4,641

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative consumer surplus to be generated by this effect amounts to US$27.01 billion between 2024 and 2034

2.2.11. A compilation of total economic value of allocating the full 6 GHz band for restricted radiation equipment use between 2024 and 2034

So far, the analysis provided the cumulative economic impact of allocating 1200 MHz in the 6 GHz band. Based on the aggregated results, the allocation of 1200 MHz in the 6 GHz for restricted radiation equipment use in Brazil will generate cumulative economic value between 2024 and 2034 reaching US$482.77 billion in additional GDP, US$119.14 in producer surplus (which includes both margins for Brazilian technology suppliers to meet local demand and savings from enterprise wireless use and capital from telecommunications carriers engaged in 5G deployment), and US$87.27 billion in consumer surplus (benefits to consumers in terms of lower cost per Mbps and faster speed) (see table 2-43).

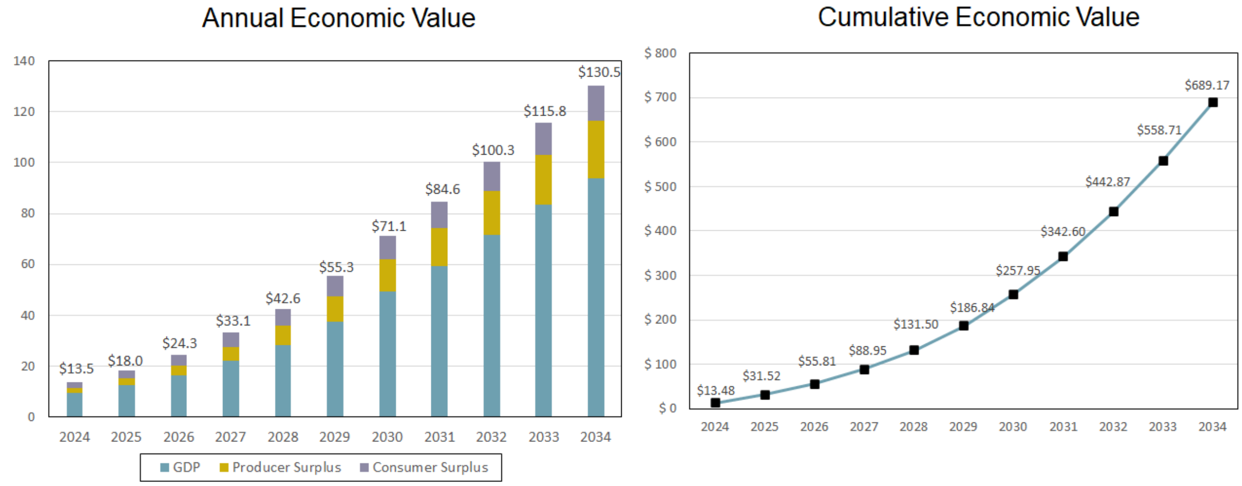
Table 2-43. Brazil: Economic Value of Allocating 1200 MHz in 6 GHz Band (2024-2034) (in US$ billion)

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in WISP sector **$ 51.88**		Faster speed of access for WISP subscribers **$ 2.88**
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi **$ 182.44**		Consumer surplus from increasing speed **$ 53.86**
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, food processing, logistics) **$ 47.69**	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment **$ 61.09**	
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications **$ 15.67**	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy **$ 186.94**	Margins of ecosystem firms involved in AR/VR deployment **$ 26.62**	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption **$ 10.74**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.35**
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption **$ 3.08**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 2.17**
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices) **$0.73**	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots **$ 3.24**	
Wi-Fi Devices and equipment		Margin of firms due to the sales of Wi-Fi Devices and Equipment **$ 11.78**	Consumer surplus from sales of Wi-Fi Devices and Equipment **$ 27.01**
TOTAL	**$ 482.77**	**$ 119.14**	**$ 87.27**

Source: Telecom Advisory Services analysis

The total economic value increases over time with significant acceleration towards the end of the period due to the leverage capability of 6 GHz (see graphic 2-5).

Graphic 2-5. Brazil: Economic value of allocating 1200 MHz in the 6 GHz band



Source: Telecom Advisory Services analysis

2.3. Difference of allocating the full 6GHz band for restricted radiation equipment use between the original study and the current estimate

As discussed in section 2.1.1. the Brazilian broadband industry underwent significant changes since the publication of the Telecom Advisory Services 2020 study on valuation of the 6 GHz band allocation for restricted radiation equipment use. The following table presents for reference only the impact that those changes had on each economic value driver for the 2021-2023 period (see table 2-44).

Table 2-44. Comparative economic impact of allocation of full 6 GHz spectrum for restricted radiation equipment use (2021-2023) (in US$ billion)

			2021	2022	2023	Total
Enhance coverage and improve affordability	GDP Contribution	2020 study	$ 0.286	$ 0.648	$ 1.066	$ 2.000
		Current study	$ 0.566	$ 1.242	$ 1.796	$ 3.604
	Consumer surplus	2020 study	$ 0.005	$ 0.018	$ 0.039	$ 0.062
		Current study	$ 0.000	$ 0.020	$ 0.021	$ 0.041
Increased speed by reducing Wi-Fi congestion	GDP Contribution	2020 study	$ 0.026	$ 0.125	$ 0.378	$ 0.529
		Current study	$ 0.235	$ 0.502	$ 1.376	$ 2.114
	Consumer surplus	2020 study	$ 0.018	$ 0.090	$ 0.274	$ 0.382
		Current study	$ 0.124	$ 0.261	$ 0.655	$ 1.041
Wide deployment of Internet of Things	Producer surplus	2020 study	$ 0.016	$ 0.082	$ 0.282	$ 0.380
		Current study	$ 0.000	$ 0.236	$ 0.518	$ 0.755
	Spillovers	2020 study	$ 0.119	$ 0.741	$ 2.734	$ 3.594
		Current study	$ 1.856	$ 3.105	$ 3.010	$ 7.971
Reduction of enterprise wireless costs	Producer surplus	2020 study	$ 0.000	$ 0.027	$ 0.119	$ 0.146
		Current study	$ 0.000	$ 0.027	$ 0.067	$ 0.094
Deployment of AR/VR solutions	Producer surplus	2020 study	$ 0.009	$ 0.030	$ 0.072	$ 0.111
		Current study	$ 0.000	$ 0.015	$ 0.045	$ 0.060
	GDP contribution	2020 study	$ 0.149	$ 0.334	$ 0.541	$ 1.023
		Current study	$ 0.000	$ 0.318	$ 0.710	$ 1.028
Enhanced deployment of municipal Wi-Fi	Consumer surplus	2020 study	$ 0.001	$ 0.003	$ 0.007	$ 0.011
		Current study	$ 0.001	$ 0.004	$ 0.006	$ 0.011
	GDP contribution	2020 study	$ 0.052	$ 0.112	$ 0.181	$ 0.346
		Current study	$ 0.039	$ 0.125	$ 0.168	$ 0.331
Deployment of Free Wi-Fi Hot Spots	Consumer surplus	2020 study	$ 0.008	$ 0.033	$ 0.072	$ 0.113
		Current study	$ 0.004	$ 0.016	$ 0.020	$ 0.040
	GDP contribution	2020 study	$ 0.038	$ 0.072	$ 0.103	$ 0.212
		Current study	$ 0.074	$ 0.140	$ 0.173	$ 0.387
Aligning spectrum decision with other advanced economies	Producer surplus	2020 study	$ 0.008	$ 0.013	$ 0.016	$ 0.038
		Current study	$ 0.023	$ 0.038	$ 0.047	$ 0.107
Total	GDP contribution	2020 study	$ 0.668	$ 2.032	$ 5.003	$ 7.704
		Current study	$ 2.770	$ 5.432	$ 7.233	$ 15.435
	Producer surplus	2020 study	$ 0.033	$ 0.152	$ 0.489	$ 0.674
		Current study	$ 0.023	$ 0.315	$ 0.677	$ 1.015
	Consumer surplus	2020 study	$ 0.032	$ 0.144	$ 0.391	$ 0.567
		Current study	$ 0.129	$ 0.301	$ 0.702	$ 1.132

The economic impact of the 6 GHz band for restricted radiation equipment use in the 2021-2023 period has seen significant growth as evidenced by the data from the 2020 study compared to the current study. The total GDP contribution nearly doubled, rising from $7.704 billion in the 2020 study to $15.435 billion in the current analysis, mainly due to the higher fixed broadband download speed as explained in section 2.1.1. Similarly, the producer surplus grew from $0.674 billion to $1.015 billion. In terms of consumer surplus there has been a substantial increase from $0.567 billion to $1.132 billion, suggesting that consumers are deriving greater value than before from the industry's products and services.

3. ECONOMIC VALUE OF ALLOCATING 500 MHz FOR RESTRICTED RADIATION EQUIPMENT USE AND 700 MHz FOR IMT

3.1. The value of allocating 500 MHz for restricted radiation equipment use

The allocation of only 500 MHz of the 6 GHz band for restricted radiation equipment use restricts the capacity of the spectrum in outdoor use and imposes a limit of indoor speed of 500 MHz. This chapter presents the resulting economic value first for restricted radiation equipment use of the lower part of the band and then for 700 MHz for IMT.

3.1.1. Enhanced broadband coverage and improved affordability

According to section 2.2.1., the 6 GHz decision would have an impact in two areas of economic value of WISPs: (i) growing consumer surplus of existing customers as a result of faster broadband service, and (ii) increasing affordability and, consequently, penetration of broadband, which in turn impacts the GDP. However, under the 500 MHz allocation alternative, it is estimated that 27.12% of total additional WISP connections will be affected by the limit put on the upper portion of the 6 GHz band in outdoor use. As detailed in Appendix A.2, in the case of restricting access to the upper part of the 6 GHz band, the first limiting aspect is the ability to accommodate more users in the 350MHz (UNII-7) that can be allowed in possible outdoor operations for WiFi 6. The 4 GHz and 5 GHz bands accommodate a maximum number of connections between 40 and 50; whereas, with the specification of the 802.11ax standard with the entire 6 GHz band, the between 110 and 120 connections could be established; that is, between 2.4 and 2.75 times more. Thus, if we take as an average scenario of WiFi 6 deployment in a 102 RU configuration, for channel aggregation with the 2.4GHz, 5 GHz and 6 GHz bands, the restriction of the latter band ($\Delta\, Cap$), would represent a 27.12% lower deployment capacity of users that would have to be hosted in the lower bands This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation scenario.

To calculate the consumer surplus under this alternative, we multiply the total economic impact under the 1200 MHz scenario by the discount factor mentioned above (see table 3-1).

Table 3-1. Consumer surplus due to WISP user speed increase under 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Impact under 1200 MHz alternative (US$ Billions)	$ 0.039	$ 0.076	$ 0.118	$ 0.164	$ 0.213	$ 0.265	$ 0.319	$ 0.361	$ 0.401	$ 0.442	$ 0.481
Discount factor	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%
Impact under 500 MHz alternative (US$ Billions)	$ 0.029	$ 0.056	$ 0.086	$ 0.120	$ 0.156	$ 0.193	$ 0.233	$ 0.263	$ 0.292	$ 0.322	$ 0.351

Sources: Telecom Advisory Services analysis

Based on the calculations of table 3-1, total 2024-2034 projected cumulative consumer surplus impact resulting from increasing broadband speed by reducing Wi-Fi congestion for WISP users amounts to US$ 2.10 billion.

In addition, the increase in affordability and broadband adoption yielded by WISPs benefitting from the 6GHz band results in a contribution to GDP, again discounted by 27.12% (see table 3-2)

Table 3-2. Brazil: GDP contribution of New WISP lines resulting from increased affordability under 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in GDP under 1200 MHz (US$ Billion)	$ 2.315	$ 2.750	$ 3.168	$ 3.622	$ 4.186	$ 4.762	$ 5.352	$ 5.774	$ 6.206	$ 6.647	$ 7.098
Discount factor	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%
Impact under 500 MHz alternative (US$ Billions)	$ 1.687	$ 2.004	$ 2.309	$ 2.640	$ 3.050	$ 3.471	$ 3.900	$ 4.208	$ 4.523	$ 4.844	$ 5.713

Sources: Telecom Advisory Services analysis.

The total cumulative impact on the GDP resulting from increased broadband penetration due to enhanced affordability and sharing is US$ 37.81 billion between 2024 and 2034.

3.1.2. Increased residential speed by reducing Wi-Fi congestion

As documented in section 2.2.2., the value to be generated by the increase in average wireless speed resulting from allocating spectrum in the 6 GHz band for all Brazilian broadband households relying on Wi-Fi connectivity in the premise translates into a contribution to the GDP and an increase in consumer surplus. However, rather than 1200 MHz availability in the full allocation scenario, under the 500 MHz allocation alternative the bottleneck effect at the in-premise router would manifest itself with broadband lines in excess of 500 Mbps. As explained in Appendix A.1., we recognize that the restriction of the 6 GHz band could establish a saturation speed accessed by users at 150 Mbps, the use of the lower part of the 6 GHz band (500 MHz) would increase the theoretical maximum speed that a user could access. Still, a constraint should exist if the number of resource units (RU) used increases beyond 500 Mbps.[35] This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation scenario.

To reiterate, 30% of Wi-Fi traffic in Brazilian residences is distributed through a router with access to the 6 GHz band, reaching 95% by 2034 (see table 3-3).

[35] For an average access scenario, in a 102 Resource Unit configuration, for the aggregation of channels with the 2.4 GHz, 5 GHz and 6 GHz bands, a value close to 86 connections could be achieved. Also, if it is considered that the maximum allowed modulation can be 1024-QAM, then the maximum speed, derived from equation 1, for 8 *spatial stream*, could be 500 Mbps.

Table 3-3. Brazil: Estimation of fixed broadband connections affected by 6 GHz decision (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Households that have connections over 150 Mbps (%)	61.08%	72.68%	84.28%	94.83%	96.19%	97.16%	97.86%	98.37%	98.75%	99.03%	99.24%
(2) Share of Home Traffic that goes through Wi Fi (%)	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%	84.50%
(3) Traffic through the 6 GHz Channel (%)	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
(4) Share of traffic affected due to 6 GHz (%)	15.48%	23.03%	32.05%	42.07%	48.77%	55.42%	62.02%	66.50%	70.93%	75.31%	79.67%

Sources: ANATEL; Ookla; Telecom Advisory Services analysis

This allocation will have an impact on Wi-Fi download speed of an incremental 350 Mbps in 2024 but remaining stable through 2034 (see table 3-4).

Table 3-4. Brazil: Estimation of fixed broadband speed in connections affected by 6 GHz decision under the 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(5) Speed of Wi Fi traffic of connections over 150 Mbps (no 6 GHz) (Mbps)	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00
(6) Speed of Wi Fi traffic of connections over 150 Mbps (with 6 GHz) (Mbps)	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
(7) Speed increase due to 6 GHz (Mbps)	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00

Sources: Telecom Advisory Services analysis

Having partially removed the spectrum bottleneck, the forecast of average fixed broadband household speed tends to grow unencumbered. This results in a speed increase of 54.19 Mbps for the average broadband connection in 2024, reaching 278.83 Mbps in 2034.

Table 3-5. Brazil: Increase in Speed resulting from 6 GHz allocation under the 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(8) Impact in speed (Mbps)	54.19	80.60	112.17	147.24	170.68	193.96	217.07	232.75	248.25	263.60	278.83
(9) Mean speed with no 6 GHz (Mbps)	359.11	399.69	426.11	438.49	459.36	473.59	481.48	497.62	509.89	517.86	521.71
(10) Mean speed with 6 GHz (Mbps)	413.30	480.30	538.28	585.74	630.04	667.55	698.55	730.37	758.14	781.45	800.54
(11) Difference due to 6 GHz	15.09%	20.17%	26.32%	33.58%	37.16%	40.96%	45.08%	46.77%	48.69%	50.90%	53.45%

Sources: Telecom Advisory Services analysis

This increase is used to calculate the impact on GDP based on the same regression models. By applying the coefficient of GDP impact of 0.73% for a 100% increase in speed, we estimate the overall GDP impact resulting from an increase in speed as a result of the partial 500 MHz allocation of the 6 GHz (see table 3-6).

Table 3-6. Brazil: Estimation of economic impact by reducing Wi-Fi congestion under the 500 MHz alternative

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(12) Impact speed on GDP	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%
(13) Increase in GDP (%)	0.11%	0.15%	0.19%	0.25%	0.27%	0.30%	0.33%	0.34%	0.36%	0.37%	0.39%
(14) Brazil GDP Billion US$	2,265	2,362	2,477	2,632	2,774	2,924	3,082	3,249	3,425	3,610	3,805
(15) Impact (US$ Billions)	$ 2.495	$ 3.477	$ 4.759	$ 6.452	$ 7.526	$ 8.743	$ 10.145	$ 11.094	$ 12.171	$ 13.413	$ 14.845

Sources: ANATEL; Cisco Virtual Networking Index

Total GDP contribution of the 6 GHz band allocation between 2024 and 2034 will reach US$ 95.12 billion.

As in the case of the return to speed analyzed above, the annual consumer surplus generated by faster Wi-Fi will also be influenced by the same trends that evolve after 2023. These trends will affect the annual contribution to faster speeds resulting from the 500 MHz allocation of the 6 GHz band as follows (see Table 3-7).

Table 3-7. Consumer Surplus from 6 GHz restricted radiation equipment under the 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Average Download Speed	359.11	399.69	426.11	438.49	459.36	473.59	481.48	497.62	509.89	517.86	521.71
(2) New Average Download Speed	413.30	480.30	538.28	585.74	630.04	667.55	698.55	730.37	758.14	781.45	800.54
(3) Demand for average download speed	93.00	94.46	95.33	95.72	96.35	96.77	96.99	97.44	97.77	97.98	98.08
(4) New Demand for average download speed	94.91	96.96	98.51	99.66	100.65	101.44	102.06	102.66	103.17	103.58	103.91
(5) Additional Monthly Consumer surplus	$1.91	$2.50	$3.18	$3.94	$4.30	$4.67	$5.06	$5.22	$5.40	$5.60	$5.83
(6) Additional Yearly Consumer Surplus	$22.95	$30.00	$38.16	$47.28	$51.60	$56.06	$60.77	$62.66	$64.78	$67.19	$69.92
(7) Fixed Broadband Connections (Millions)	50.144	53.024	55.821	58.336	58.619	58.891	59.163	59.437	59.713	59.989	60.267
(8) Impact (US$ Millions)	$1,151	$1,591	$2,130	$2,758	$3,025	$3,301	$3,596	$3,725	$3,868	$4,031	$4,214

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

The increase of the average household in consumer surplus evolves from US$1,151 million in 2024 to US$4,214 million in 2034; this is the value multiplied by the total number of connections. In sum, total consumer surplus associated with the 6 GHz band between 2024 and 2034 will reach $33.39 billion.

3.1.3. Wide deployment of Internet of Things

As detailed in section 2.2.3., the enhanced deployment of IoT due to the 6 GHz allocation to restricted radiation equipment use will trigger two economic effects: (i) the generation of producer surplus (i.e. margins) of Brazilian eco-system suppliers in the IoT segment, and (ii) the spillover of IoT on the efficiency of Brazilian industries. As documented in appendix A.3, it is assumed that under the 500 MHz allocation alternative, 58.33% of the revenues of the IoT equipment that operate indoors and outdoors will be eliminated. According to *Statista Market Insights*, the revenue market by IoT segment in Brazil, by 2023, is mostly represented by indoor deployments (65.15%); while 34.85% could be considered IoT developments compatible with large areas (Industrial IoT and Smart Cities). Consequently, if the proportion of spectrum that could be restricted in the high 6 GHz band corresponds to 58.33% of the total (of the 1200 MHz available for outdoor applications in the 6 GHz band, the 700 MHz corresponding to the high band represents 58.33%). This has a negative impact on GDP contribution and producer surplus as estimated under the whole band allocation scenario.

Table 3-8. Producer Surplus of IoT deployment from 6 GHz restricted radiation equipment under the 500 MHz alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Indoors revenue	32.66%	30.98%	29.63%	28.50%	27.68%	26.31%	25.12%	24.09%	23.20%	22.43%	21.76%
Higher part of the band restricted (indoor)	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact indoor ecosystem	19.05%	18.07%	17.28%	16.62%	16.15%	15.35%	14.65%	14.05%	13.53%	13.08%	12.69%
Total Impact indoor + outdoor	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Final Economic Impact	0.37	0.58	0.86	1.26	1.78	2.36	2.99	3.38	3.71	3.98	4.19

Source: CSI Insights; ABI Research; Telecom Advisory Services analysis

Based on the sum of annual values, the total cumulative value of producer surplus driven by sales of IoT by Brazilian firms in Brazil under the 500 MHz allocation alternative between 2024 and 2034 amounts to US$25.46 billion.

In addition, IoT adoption contributes to GDP growth through the multiplicity of use cases that improve efficiency in processes such as preventive maintenance and production monitoring.

Table 3-9. Brazil: IoT Spillover under 500 MHz of the 6 GHz spectrum allocation (in US$ billion) (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Indoors IoT revenue	32.66%	30.98%	29.63%	28.50%	27.68%	26.31%	25.12%	24.09%	23.20%	22.43%	21.76%
Higher part of the band restricted (indoor)	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact indoor ecosystem	19.05%	18.07%	17.28%	16.62%	16.15%	15.35%	14.65%	14.05%	13.53%	13.08%	12.69%
Total Impact indoor + outdoor	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Final Economic Impact (US$ billion)	1.27	1.28	1.37	1.51	1.51	1.76	2.06	1.80	2.11	2.43	2.77

Source: GSMA Intelligence; Statista Market Insights; Frontier Economics; Telecom Advisory Services analysis

According to the annual estimates, cumulative spillover impact of enhanced IoT deployment driven by 6 GHz spectrum total allocation for restricted radiation equipment use will reach US$19.87 billion between 2024 and 2034.

3.1.4. Reduction of enterprise wireless costs

As explained in section 2.2.4, the allocation of 6 GHz also has an economic effect in enterprise margins (or producer surplus), in terms of the savings from cellular usage implied by using restricted radiation equipment spectrum to handle traffic from high-capacity Wi-Fi devices rather than cellular networks. However, under the 500 MHz allocation alternative, the bottleneck effect at the in-premise router would manifest itself with broadband lines in excess of 500 Mbps. This has an impact on the producer surplus estimation under the whole band allocation scenario.

Table 3-10. Brazil: Impact on enterprise wireless under the 500 MHz allocation alternative (2024-2034) (in '000'000 US$)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
Economic impact of 1200 MHz of the 6 GHz Band (US$ Billion)	$ 0.150	$ 0.265	$ 0.418	$ 0.612	$ 0.854	$ 1.152	$ 1.515	$ 1.898	$ 2.354	$ 2.899	$ 3.551
Difference in return to speed	100.00%	87.50%	77.78%	70.00%	63.64%	58.33%	53.85%	50.00%	46.67%	43.75%	41.18%
Economic impact of 500 MHz of the 6 GHz Band (US$ Billion)	$ 0.150	$ 0.232	$ 0.325	$ 0.428	$ 0.543	$ 0.672	$ 0.816	$ 0.949	$ 1.098	$ 1.268	$ 1.462

Source: Telecom Advisory Services analysis

The sum of the difference due to broader Wi-Fi traffic between 2024 and 2034 will reach US$ 7.945 billion.

3.1.5. Deployment of AR/VR solutions

As discussed in section 2.2.5., the development and diffusion of AR/VR applications in the production side of the economy is being driven by an ecosystem comprised of firms ranging from software development to hardware production and content creation. In this context, it is relevant to estimate whether a scenario of allocating only 500 MHz of the 6 GHz band for restricted radiation equipment use will have a diminishing effect on the producer surplus generated in Brazil because of the sales of AR/VR applications produced by domestic firms.

Under the 500 MHz allocation alternative, it is estimated that the estimated value for the allocation of the whole band would be reduced by 58.33% for indoor and outdoor environments. This has a negative impact on GDP contribution and producer surplus as estimated under the whole band allocation scenario.

Table 3-11. Brazil: Producer surplus derived from AR/VR sales by Brazilian firms by component under 500 MHz of the 6 GHz spectrum allocation (2024-2034) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Full 6 GHz band	$ 0.11	$ 0.22	$ 0.42	$ 0.76	$ 1.19	$ 1.80	$ 2.60	$ 3.37	$ 4.28	$ 5.33	$ 6.55
Indoor Usage	47.44%	47.91%	48.69%	48.90%	48.51%	47.84%	47.00%	47.00%	47.00%	47.00%	47.00%
Higher part of the band restricted for indoor	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact indoor ecosystem	27.67%	27.95%	28.40%	28.53%	28.30%	27.91%	27.42%	27.42%	27.42%	27.42%	27.42%
Impact outdoor ecosystem	30.66%	30.39%	29.93%	29.81%	30.03%	30.43%	30.92%	30.92%	30.92%	30.92%	30.92%
Total Impact	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Economic Impact	$ 0.04	$ 0.09	$ 0.18	$ 0.32	$ 0.49	$ 0.75	$ 1.08	$ 1.40	$ 1.78	$ 2.22	$ 2.73

Source: CSI Market Inc*: Industry Profitability ratios; ABI Research; Telecom Advisory Services analysis*

Based on this estimate, the total producer surplus value of AR/VR in Brazil (the direct impact) under the 500 MHz allocation alternative between 2024 and 2034 is US$11.09 billion.

Furthermore, the adoption of AR/VR among Brazilian businesses will, in turn, have a spillover effect on productivity, thereby contributing to the growth of GDP (see table 3-12).

Table 3-12. Brazil: GDP Contribution resulting from AR/VR Spillovers under 500 MHz of the 6 GHz spectrum allocation (2024-2034) (in US$ billion)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Indirect impact	$ 1.25	$ 1.94	$ 2.93	$ 4.64	$ 7.58	$ 12.23	$ 18.61	$ 25.51	$ 32.34	$ 38.13	$ 41.78
Indoor Usage	47.44%	47.91%	48.69%	48.90%	48.51%	47.84%	47.00%	47.00%	47.00%	47.00%	47.00%
Higher part of the band	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact	27.67%	27.95%	28.40%	28.53%	28.30%	27.91%	27.42%	27.42%	27.42%	27.42%	27.42%
Impact outdoor	30.66%	30.39%	29.93%	29.81%	30.03%	30.43%	30.92%	30.92%	30.92%	30.92%	30.92%
Total Impact	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact	$ 0.52	$ 0.81	$ 1.22	$ 1.93	$ 3.16	$ 5.10	$ 7.76	$ 10.63	$ 13.47	$ 15.89	$ 17.41

Source: ABI Research; CSI Market Inc*: Industry Profitability ratios; Telecom Advisory Services analysis.*

Based on this estimate, the total spillover value of AR/VR in Brazil (the indirect impact) under the 500 MHz allocation alternative between 2024 and 2034 will be US$ 77.89 billion.

3.1.6. Enhanced deployment of municipal Wi-Fi

As reported in section 2.2.6, municipal Wi-Fi can play a role in enhancing broadband service coverage by providing a free resource for consumers to gain access to the Internet. Along these lines, allocating spectrum in the 6 GHz band will increase the ability of municipal Wi-Fi to provide free service to unserved population or increase the speed of access for current users. These two effects translate into a contribution to GDP and an increase in consumer surplus. That said, according to Appendix A.5., under the 500 MHz allocation alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation scenario.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP[36], discounted by the limits imposed on outdoor traffic, yields the GDP impact of Municipal Wi-Fi (see table 3-13).

Table 3-13. Brazil: GDP impact of Municipal Wi-Fi networks under 500 MHz of the 6 GHz spectrum allocation

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total GDP impact GDP under 1200 MHz alternative (US$ Billion)	$ 0.239	$ 0.315	$ 0.401	$ 0.509	$ 0.653	$ 0.826	$ 1.033	$ 1.251	$ 1.511	$ 1.820	$ 2.186
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
(15') Total impact in GDP under 500 MHz alternative (US$ Billion)	0.180	0.236	0.302	0.383	0.491	0.621	0.776	0.941	1.136	1.368	1.643

Source: IMF; ITU; Telecom Advisory Services analysis.

In sum, the cumulative contribution of GDP of the benefit accorded to municipal Wi-Fi networks by allocating spectrum in the 6 GHz band will reach US$ 8.077 billion between 2024 and 2034.

In addition to the contribution to GDP, municipal Wi-Fi networks with the capacity to leverage spectrum in 6 GHz can enhance their performance, providing faster broadband service, and thereby generating incremental consumer surplus. Again, relying on the discounting factor of 24.82% allows calculating the impact of municipal Wi-Fi on consumer surplus.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP, discounted by the limits imposed on outdoor traffic, yields the GDP impact of Municipal Wi-Fi (see table 3-14).

Table 3-14. Brazil: Consumer surplus of households benefitting from municipal Wi-Fi under 500 MHz of the 6 GHz spectrum allocation

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in consumer surplus under 1200 MHz alternative (US$ Billion)	$ 0.011	$ 0.019	$ 0.030	$ 0.044	$ 0.063	$ 0.087	$ 0.120	$ 0.157	$ 0.205	$ 0.266	$ 0.345
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
Total impact on consumer surplus under 500 MHz alternative (US$ Billion)	0.009	0.014	0.022	0.033	0.047	0.066	0.090	0.118	0.154	0.200	0.259

Source: IMF; ITU; Telecom Advisory Services analysis.

[36] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

The cumulative consumer surplus to be generated by this effect amounts to US$ 1.013 billion between 2024 and 2034.

3.1.7. Deployment of free Wi-Fi spots

Free Wi-Fi hot spots that benefit from 6 GHz spectrum will be capable of handling a higher number of devices, which in turn will contribute to broadband adoption. On the other hand, these sites will be able to deliver faster speed of service, which can be transferred to increasing consumer well-being. However, as in the case of municipal Wi-Fi, under the 500 MHz allocation alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation alternative.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP[37], discounted by the limits imposed on outdoor traffic, yields the GDP impact of Municipal Wi-Fi (see table 3-14).

Table 3-14. Brazil: GDP impact of Free Wi-Fi networks under 500 MHz of the 6 GHz spectrum allocation

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total GDP impact GDP under 1200 MHz alternative (US$ Billion)	0.217	0.250	0.277	0.301	0.325	0.339	0.339	0.324	0.294	0.243	0.167
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
(15') Total impact in GDP under 500 MHz alternative (US$ Billion)	0.163	0.188	0.208	0.226	0.245	0.255	0.255	0.244	0.221	0.183	0.125

Source: IMF; ITU; Telecom Advisory Services analysis.

In sum, the cumulative contribution of GDP of the benefit accorded to municipal Wi-Fi networks by allocating spectrum in the 6 GHz band will reach US$ 2.313 billion between 2024 and 2034.

In addition to the contribution to GDP, free Wi-Fi networks with the capacity to leverage spectrum in 6 GHz can enhance their performance, providing faster broadband service, and thereby generating incremental consumer surplus. Again, relying on the discounting factor of 24.82% due to the 500 MHz alternative allows calculating the impact of free Wi-Fi on consumer surplus.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP, discounted by the limits imposed on outdoor traffic, yields the GDP impact of Municipal Wi-Fi (see table 3-15).

[37] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

Table 3-15. Brazil: Consumer surplus of households benefitting from Free Wi-Fi under 500 MHz of the 6 GHz band (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in consumer surplus under 1200 MHz alternative (US$ Billion)	0.035	0.053	0.075	0.102	0.134	0.172	0.216	0.259	0.310	0.370	0.440
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
Total impact on consumer surplus under 500 MHz alternative (US$ Billion)	0.026	0.040	0.057	0.077	0.101	0.129	0.162	0.195	0.233	0.278	0.331

Source: IMF; ITU; Telecom Advisory Services analysis.

The cumulative consumer surplus to be generated by this effect amounts to US$ 1.629 billion between 2024 and 2034.

3.1.8. Aligning spectrum decision with other advanced economies

Under this scenario, no alignment would occur with the decisions made by other advanced economies such as the United States, Canada, and South Korea. Consequently, no economic value would be registered under this effect.

3.1.9. Enhancing the capability for cellular off-loading

The key objective is to estimate the savings in capital investment as a result of an increase in traffic offloading with Wi-Fi benefits from the additional spectrum in the 6 GHz band, but more importantly, the ability to leverage 160 MHz within a single contiguous channel. However, under the 500 MHz allocation alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on the producer surplus as estimated under the whole band allocation scenario. From an estimated benefit between 2024 and 2034 if 1200 MHz were to be assigned to restricted radiation equipment use (producer surplus: US$ 3.24 billion), the benefit under a 500 MHz scenario would amount to US$ 2.44 billion.

3.1.10. Wi-Fi Devices and equipment

The development of a Brazilian industry focused on manufacturing Wi-Fi devices and equipment stimulated by the allocation of 6 GHz band would benefit from a producer surplus. Apart from the producer surplus generated by Wi-Fi devices and equipment in Brazil, there is also the creation of a consumer surplus, which represents the difference between what Brazilian consumers are willing to pay and what they actually spend. Under the 500 MHz allocation alternative, the proportional part of the incremental sales of restricted radiation equipment for outdoor environments that could not be used would be reduced by 2.77%. In addition, there would be a reduction in indoors Wi-Fi equipment due to speed congestion (Devices with congestion * Wi-Fi congestion).

Under these assumptions, we estimate the producer surplus from Wi-Fi devices and equipment in Brazil between 2024 and 2034 (see table 3-16).

Table 3-16. Producer surplus from Wi-Fi devices and equipment by allocating 500 MHz in 6 GHz Band (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Reduction in impact return to speed	0.00%	12.50%	22.22%	30.00%	36.36%	41.67%	46.15%	50.00%	53.33%	56.25%	58.82%
Incremental sales, relative to return to speed	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%
Reduction in sales	0.00%	2.57%	4.57%	6.17%	7.47%	8.56%	9.49%	10.28%	10.96%	11.56%	12.09%
Sales reduction due to outdoors	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%
Total sales reduction	2.77%	5.33%	7.33%	8.93%	10.24%	11.33%	12.25%	13.04%	13.73%	14.33%	14.86%
Producer surplus 500 MHz	$240	$350	$462	$571	$680	$789	$899	$1,011	$1,139	$1,284	$1,448

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative producer surplus to be generated by this effect amounts to US$8.873 billion between 2024 and 2034.

Furthermore, we estimate the consumer surplus from Wi-Fi devices and equipment in Brazil between 2024 and 2034 (see table 3-17).

Table 3-17. Consumer surplus from Wi-Fi devices and equipment by allocating 500 MHz in 6 GHz Band (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Reduction in impact return to speed	0.00%	12.50%	22.22%	30.00%	36.36%	41.67%	46.15%	50.00%	53.33%	56.25%	58.82%
Incremental sales, relative to return to speed	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%	20.56%
Reduction in sales	0.00%	2.57%	4.57%	6.17%	7.47%	8.56%	9.49%	10.28%	10.96%	11.56%	12.09%
Sales reduction due to outdoors	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%
Total sales reduction	2.77%	5.33%	7.33%	8.93%	10.24%	11.33%	12.25%	13.04%	13.73%	14.33%	14.86%
Producer surplus 500 MHz	$762	$1,004	$1,246	$1,511	$1,773	$2,044	$2,326	$2,652	$3,026	$3,457	$3,952

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative consumer surplus to be generated by this effect amounts to US$ 23.75 billion between 2024 and 2034.

3.1.11. A compilation of economic value of 500 MHz for unlicensed use

So far, the analyses by value source estimate the cumulative economic impact of allocating 500MHz in the 6 GHz band. Based on the aggregated results, the allocation of 500 MHz in the 6 GHz for unlicensed use in Brazil will generate cumulative economic value between 2024 and 2034 reaching US$241.08 billion in additional GDP, US$55.81 in producer surplus (which includes both margins for Brazilian technology suppliers to meet local demand and savings from enterprise wireless use and capital from telecommunications carriers engaged in 5G deployment), and US$61.88 billion in consumer surplus (benefits to consumers in terms of lower cost per Mbps and faster speed) (see table 3-18).

Table 3-18. Brazil: Economic Value of Allocating 500 MHz in 6 GHz Band (2024-2034) (in US$ billion)

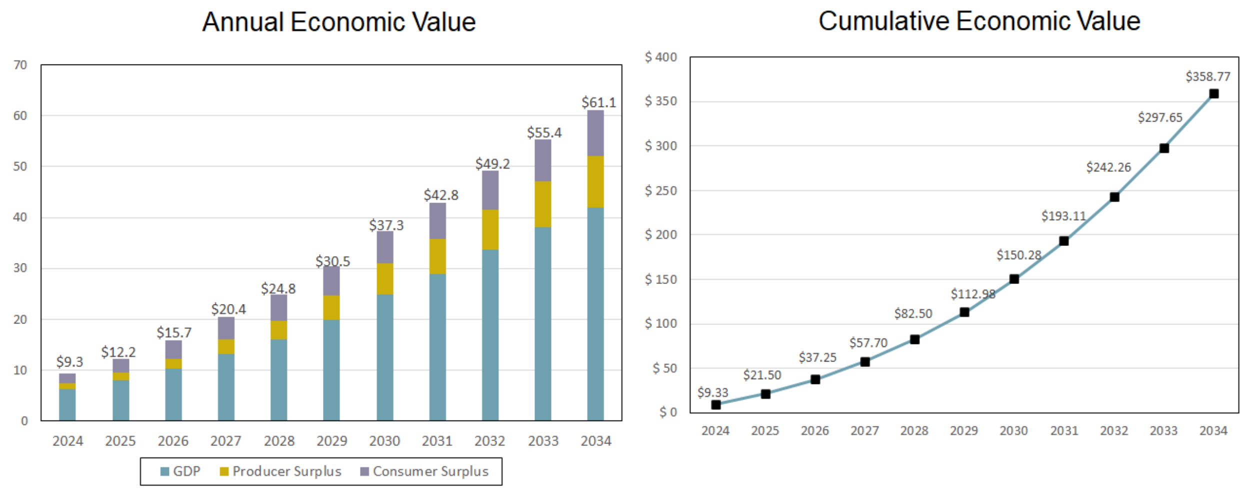
Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in WISP sector **$ 37.81**		Faster speed of access for WISP subscribers **$ 2.10**
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi **$ 95.12**		Consumer surplus from increasing speed **$ 33.39**
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, food processing, logistics) **$ 19.87**	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment **$ 25.46**	
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications **$ 7.94**	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy **$ 77.89**	Margins of ecosystem firms involved in AR/VR deployment **$ 11.09**	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption **$ 8.08**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.01**
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption **$ 2.31**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.63**
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices) **$0.00**	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots **$ 2.44**	

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Wi-Fi Devices and equipment	[redacted]	Margin of firms due to the sales of Wi-Fi Devices and Equipment **$ 8.87**	Consumer surplus from sales of Wi-Fi Devices and Equipment **$ 23.75**
TOTAL	**$ 241.08**	**$ 55.81**	**$ 61.88**

Source: Telecom Advisory Services analysis

The total economic value increases over time with significant acceleration towards the end of the period due to the leverage capability of 6 GHz (see graphic 3-1).

Graphic 3-1. Brazil: Economic value of allocating 500 MHz in the 6 GHz band



Source: Telecom Advisory Services analysis

3.2. Value of allocating the upper 700 MHz to IMT

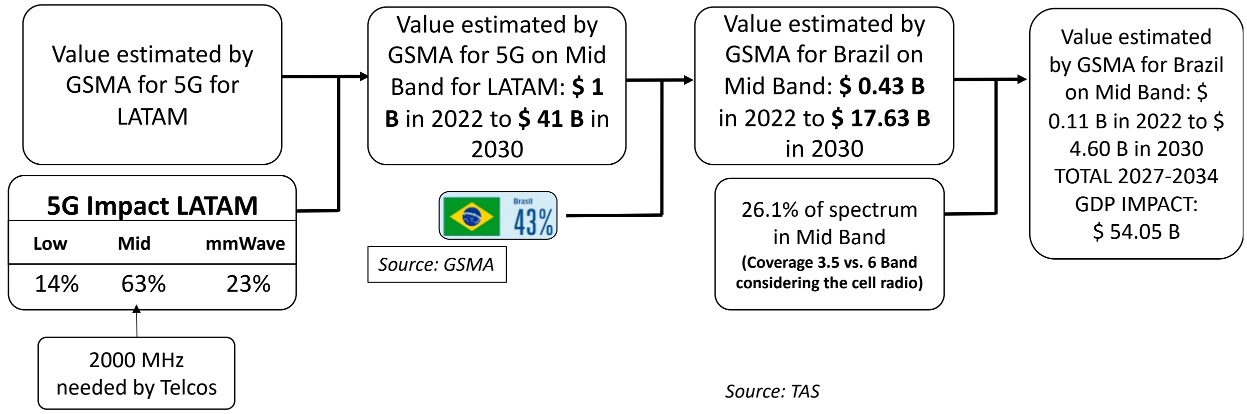
Part of the negative economic impact of limiting access of the 6 GHz band for unlicensed use is mitigated by the benefits resulting from allocating 700 MHz to IMT. These benefits can also be categorized in terms of GDP contribution, producer surplus, and consumer surplus.

3.2.1. GDP contribution

The GSMA estimates that the allocation of mid bands to IMT in Brazil would generate a GDP contribution of US$ 1 Billion in 2022, and US$ 41 billion in 2030.[38] We prorate this amount to reflect the 700 MHz portion that IMT players would receive under this alternative (see figure 3-1).

[38] Source: GSMA (2022). The Socio-Economic Benefits of Mid-Band 5G Services. https://www.gsma.com/spectrum/wp-content/uploads/2022/02/mid-band-5G-spectrum-benefits.pdf

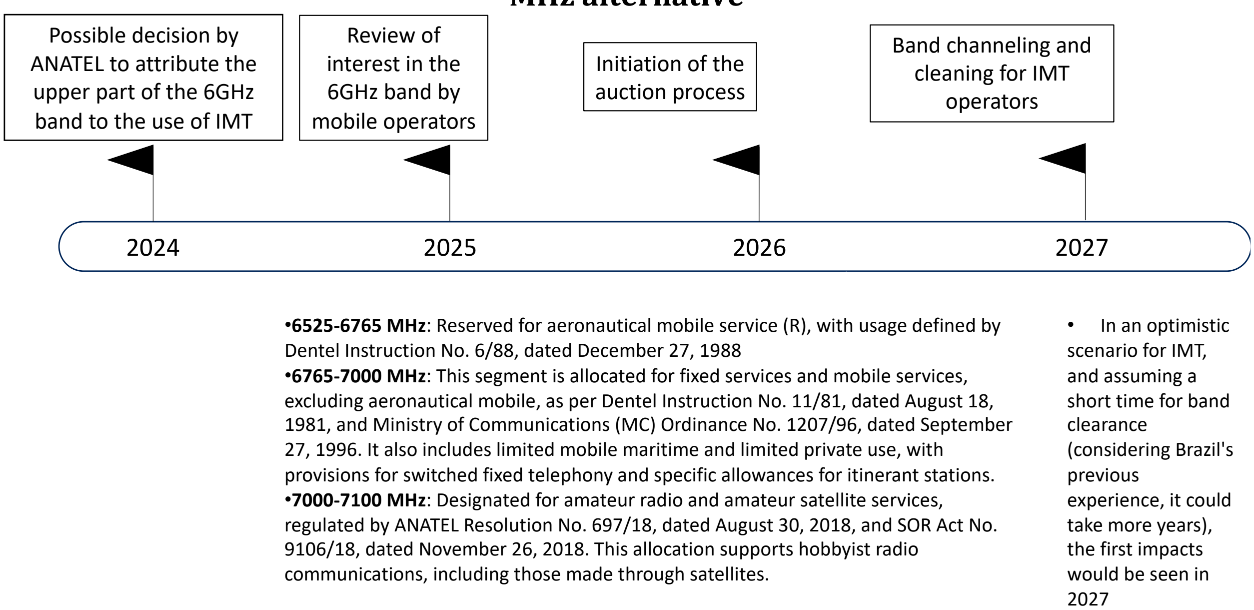
Figure 3-1. GDP impact to be generated by IMT players under the allocation of 700 MHz alternative



Source: GSMA

We also assume that 5G service on this band could only be launched in 2027 due to cleaning of the band and auction completion (see figure 3-2).

Figure 3-2. GDP impact to be generated by IMT players under the allocation of 700 MHz alternative



Source: ANATEL from https://informacoes.anatel.gov.br/legislacao/resolucoes/2023/1834-resolucao-759

In sum, total GDP contribution between 2027 and 2034 will reach US$ 54.05 billion.

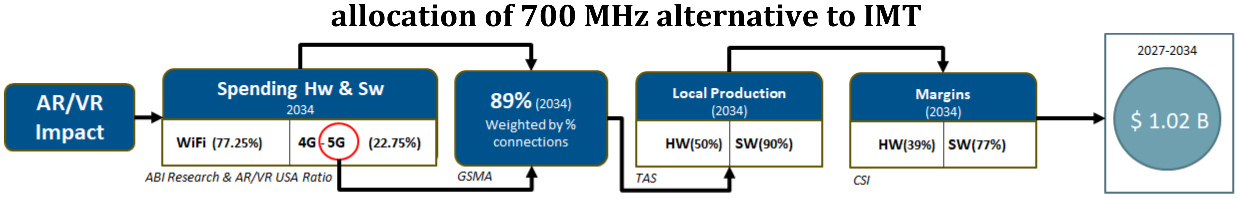
3.2.2. Producer surplus

The effect of the producer surplus associated with the local AR/VR industry is assumed such that all economic value not attributable to Wi-Fi can be attributed to the mobile network segment (i.e., through 4G and 5G technologies).

Starting from the total AR/VR sales in Brazil, the percentage attributable to the mobile segment, which is assumed to remain constant at one quarter of the Wi-Fi segment, is calculated. Considering the significance of 5G networks within the total mobile segment, it is estimated that by the end of the analyzed period, 20.3% of the economic value of this industry can be attributed to this technology. Applying the local production ratios and margins (in a manner analogous to the analysis conducted for Wi-Fi), it is possible to estimate the producer surplus attributable to 5G. However, it is necessary to consider only the portion of this that can be attributed to the allocation of 700 MHz of the 6 GHz band for 5G. As a proxy for such a percentage, the estimates of GSMA (2022) are considered, which forecast that globally the impact of 5G on the economy will be US$ 961 billion, of which US$ 611 billion can be attributed to the allocation of 2000 MHz in mid-bands. By apportioning the value attributed to mid-bands, the allocation of 700 MHz would generate US$ 54.05 billion (2027-2034), representing 16.44% of the total economic value generated by 5G by the year 2030. This percentage is applied to the producer surplus of the AR/VR industry to estimate the corresponding value attributable to the partial allocation of the 6 GHz band.

Thus, the producer surplus attributable to the effect of the 6 GHz band for 5G on the local production of AR/VR, accumulated over the period 2027-2034, amounts to US$ 1.02 billion (see Figure 3-3).

Figure 3-3. Methodology for calculating AR/VR producer surplus under the allocation of 700 MHz alternative to IMT

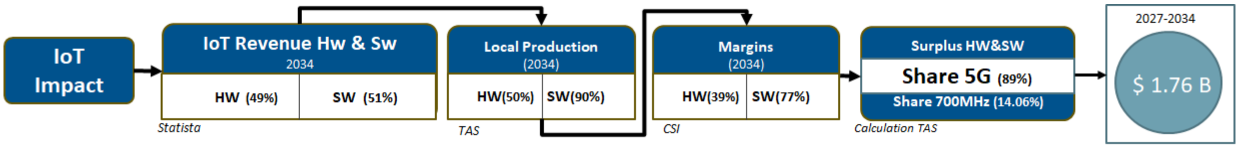


Source: Telecom Advisory Services based on ABI Research

The analysis of the producer surplus associated with the IoT industry is conducted in a manner similar to that of the AR/VR case. The total producer surplus is calculated from the IoT revenue market in the Brazilian market, considering an almost equitable portion between the Hardware sector (49.09%) and Software (50.91%) for the year 2034.

On the other hand, it is assumed that of the total devices that could operate for IoT, 20.3% can be attributed to 5G by the year 2034; and, of the total attributable to 5G, 16.44% is assumed to correspond to the allocation of 700 MHz in the 6 GHz band. Thus, the cumulative value during the period 2027-2034 amounts to US$ 1.76 billion (see Figure 3-4).

Figure 3-4. Methodology for calculating IoT in producer surplus under the allocation of 700 MHz alternative to IMT



Source: Telecom Advisory Services based on Statista Market Insights and CSI

In total, by gaining access to 700 MHz, wireless service providers could generate US$ 2.78 in producer surplus (primarily in IoT and AR/VR deployment).

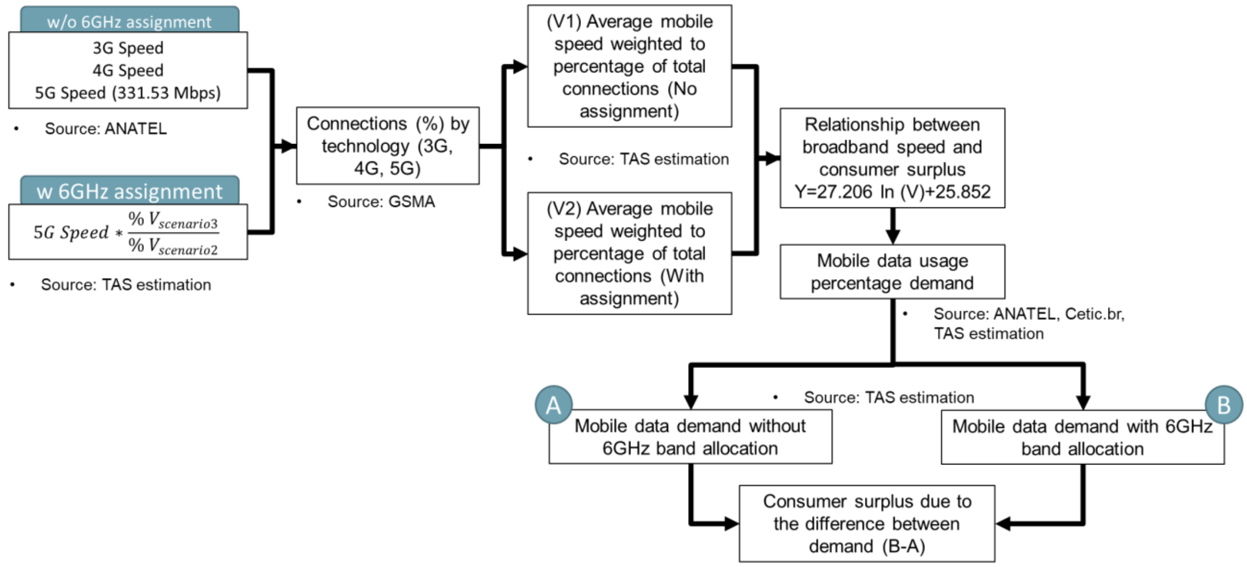
3.2.3. Consumer surplus

Regarding the sources of value linked to consumer surplus, two aspects are considered: (i) the speed increases of 5G attributable to the allocation of additional spectrum that will generate value for consumers; and, (ii) the acquisition of smartphones suitable for the use of 5G in the 6 GHz band that will generate value for users to the extent that their willingness to pay for them is above the cost. On the other hand, no effect is assumed in terms of coverage increases, since 5G is not expected to be available in rural areas during the considered period, nor is an economic effect attributed to free or municipal connection points, since these primarily utilize Wi-Fi technology.

Regarding the increase in speed, the starting point of this analysis stems from the projections of average mobile speeds for 3G, 4G, and 5G from mobile operators registered on the ANATEL website, taken for one of the most populous municipalities such as Rio de Janeiro (3531.53 Mbps). From there, based on information from GSMA (2022a), the relationship between the maximum speed rate percentage for 5G technology in a shared scenario of the 6GHz band with WiFi and without sharing is obtained. That is, the projected speed for 5G, assuming that 700MHz are allocated, corresponds to the current 5G speed (331.53 Mbps based on ANATEL data for Rio de Janeiro) multiplied by the speed increase projected by GSMA.

In this sense, the average mobile speed weighted by the percentage of mobile connections in both scenarios (with partial allocation of the 6 GHz band for 5G, and without it) is calculated, and the demand for 5G (also in both scenarios) is calculated from the percentage of mobile data usage to, finally, assess consumers' willingness to pay in each case, the difference being the consumer surplus that can be attributed to allocating this portion of the spectrum for IMT (see Figure 3-5).

Figure 3-5. Methodology for calculating consumer surplus due to speed change under the allocation of 700 MHz alternative to IMT

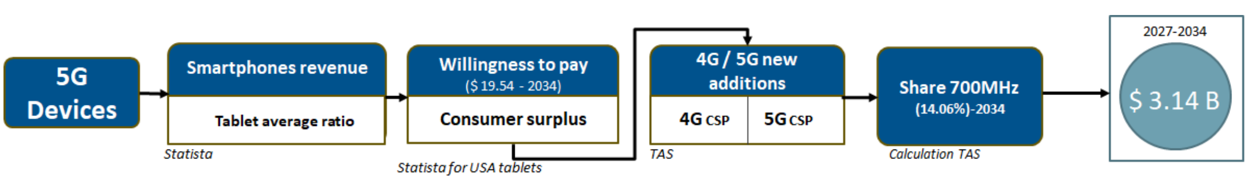


Source: Telecom Advisory Services based on GSMA and ANATEL

Accordingly, consumer surplus from speed improvement can be valued at US$16.78 billion over the entire period.

Smartphone sales in Brazil can be valued at US$ 16.57 billion in 2023 (Source: Statista Market Insights) and are expected to grow at an average annual compound rate of 0.52%. Thus, it is feasible to project that sales will reach US$ 17 billion by 2034. Applying the same value as tablets (Source: Statista), it can be assumed that the users' willingness to pay is 1.15 times higher than pricing, from which it follows that it would take a value of US$ 19.54 billion in 2034. The difference between the willingness to pay and what is paid equals the consumer surplus, which would amount to US$ 2.54 billion at the end of the period. Such value should be apportioned among new 4G and 5G connections, and within the latter, it is assumed that 14.06% can be attributed to terminals enabled for the use of the 6 GHz band in 5G. Thus, the cumulative sum of the consumer surplus attributable to smartphones using the 6 GHz band amounts to US$ 3.14 billion over the considered period (See Figure 3-6).

Figure 3-6. Methodology for calculating residential equipment in consumer surplus under the allocation of 700 MHz alternative to IMT



Fuente: Telecom Advisory Services based on Statista

3.2.4. Mid-band auction proceeds

Finally, under the alternative that IMT players were to be allocated 700 MHz of the 6 GHz band, it is fair to assume that a potential auction could generate additional proceeds. We have estimated this amount based on the proceeds of the 3.5 auction in Brazil in 2021 (see table 3-19).

Table 3-19. Estimate of 700 MHz in the 6GHz auction proceeds

Variable	Spectrum amount	Total proceeds (US$)	Amount per MHz (US$)
3.5 GHz Auction (2021)	300 MHz	$ 250.50	$ 0.84
Investment commitmentds		$ 4,731.90	$ 15.77
Total 3.5 GHz auction	300 MHz	$ 4,982.40	$ 16.61
Extrapolation to 700 MHz in 6 GHz	700 MHz	$ 11,625.60	$ 16.61

Fuente: Telecom Advisory Services

Under the best scenario, one can assume that auction proceeds will be reinvested in network deployment, which would result in a total value of US$ 11.63 billion (primarily in commitments to invest in network deployment). Considering this value in the final economic impact may carry the risk of double counting with the impact on GDP, as if the spectrum payment occurs in commitments, that would already be accounted for in the impact on the 5G GDP. In the event it occurs as a transfer to the government, it is a monetary transfer, without impact on the economic value calculation.

3.3. A compilation of total economic value of allocating 500 MHz for unlicensed use and 700 MHz for IMT

So far, the analyses by value source estimate the cumulative economic impact of allocating 500MHz in the 6 GHz band. Based on the aggregated results, the allocation of 500 MHz in the 6 GHz for unlicensed use in Brazil will generate cumulative economic value between 2024 and 2034 reaching US$241.08 billion in additional GDP, US$55.81 billion in producer surplus (which includes both margins for Brazilian technology suppliers to meet local demand and savings from enterprise wireless use and capital from telecommunications carriers engaged in 5G deployment), and US$61.88 billion in consumer surplus (benefits to consumers in terms of lower cost per Mbps and faster speed) (see table 3-20).

Table 3-20. Brazil: Economic Value of Allocating 500 MHz in 6 GHz Band (2024-2034) (in US$ billion)

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in WISP sector **$ 37.81**		Faster speed of access for WISP subscribers **$ 2.10**
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi **$ 95.12**		Consumer surplus from increasing speed **$ 33.39**
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, food processing, logistics)	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment **$ 25.46**	

Source of Value	GDP contribution	Producer surplus	Consumer surplus
	$ 19.87		
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications **$ 7.94**	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy **$ 77.89**	Margins of ecosystem firms involved in AR/VR deployment **$ 11.09**	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption **$ 8.08**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.01**
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption **$ 2.31**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.63**
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices) **$0.00**	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots **$ 2.44**	
Wi-Fi Devices and equipment		Margin of firms due to the sales of Wi-Fi Devices and Equipment **$ 8.87**	Consumer surplus from sales of Wi-Fi Devices and Equipment **$ 23.75**
TOTAL	**$ 241.08**	**$ 55.81**	**$ 61.88**

Source: Telecom Advisory Services analysis

Further, the economic value if the upper band is allocated to IMT amounts to US$ 54.05 Billion in GDP contribution, US$ 2.78 Billion in producer surplus, and US$ 19.92 Billion in consumer surplus to the Brazilian consumers (see table 3-21).

Table 3-21. Economic value of allocating 700 MHz in the 6 GHz band indoors – outdoors for IMT (2024-2034) (in US$ billions)

Source of Value	GDP contribution	Producer surplus	Consumer surplus
I. Enhance coverage and improve affordability	$54.05 (GSMA)		
2. Increased speed by reducing Wi-Fi congestion			$ 16.78
3. Wide deployment of Internet of Things		$ 1.76	
4. Reduction of enterprise wireless costs			
5. Deployment of AR/VR solutions		$ 1.02	
6. Enhanced deployment of municipal Wi-Fi			
7. Deployment of Free Wi-Fi Hot Spots			
8. Aligning spectrum decision with other advanced economies			
9. Enhancing the capability for cellular off-loading			
10. Wi-Fi Devices and equipment			$ 3.14
TOTAL	**$ 54.05**	**$ 2.78**	**$ 19.92**

Fuente: Telecom Advisory Services

An additional benefit exists due to the auction potential of the 700 MHz spectrum, which is estimated at US$ 11.63 billion (primarily in commitments).

In sum, the total value of the economic impact of the partial allocation of the 6 GHz band for IMT (GDP, producer, and consumer surplus), has two important quantitative elements: (i) this scenario (700MHz - IMT), on its own , is 87.18% lower than the impact generated by the total allocation to the band for Wi-Fi (1200 MHz); (ii) The combination of this scenario (700MHz -IMT) together with the allocation of the low 6 GHz zone for Wi-Fi (500MHz) is 35.12% lower than the impact generated by the total allocation to Wi-Fi (1200 MHz) (see Table 3-22)

Table 3-22. Analysis of the 6GHz band allocation – Wi-Fi (500MHz) + IMT (700MHz) (700MHz)

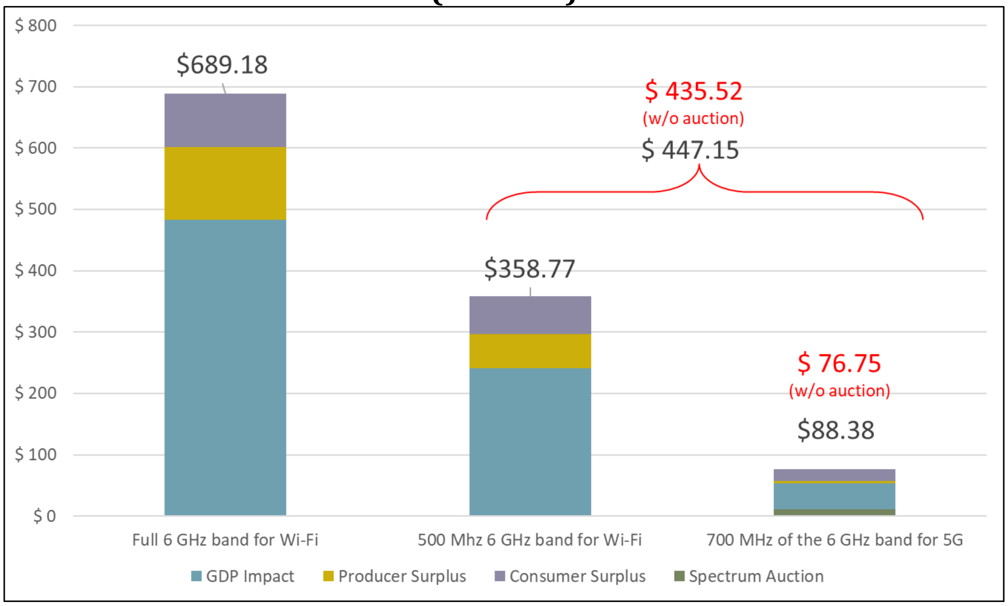
Scenario	GDP Impact	Producer Surplus	Consumer Surplus	Spectrum Auction	TOTAL
Full 6 GHz band for unlicensed use	$482.77	$119.14	$87.27	$0.00	$689.18
500 MHz 6 GHz band for unlicensed use	$241.08	$55.81	$61.88	$0.00	$358.77
700 MHz of the 6 GHz band for IMT	$54.05	$2.78	$19.92	$11.63	$88.38

Source: Telecom Advisory Services Analysis

In comparison with the proposed scenario for the allocation of the 6 GHz band for unlicensed use, we can draw the following conclusions:

- The difference in economic impact ($330.41 billion) between the full ($689.18 billion) and partial ($358.77 billion) allocation of the 6 GHz band for Wi-Fi is larger than the expected effects of the partial allocation for 5G ($88.38 billion) (see Figure 3-7).
- To analyze the impact of 5G, it would be expected that the economic effect begins in 2027 in an optimistic scenario; Meanwhile, the unlicensed use allocation starts having an effect from the first years.
- Wi-Fi has the advantage of generating an immediate economic impact and has greater potential to increase coverage in rural areas.

Figure 3-7. Comparison between 6GHz band allocation – WiFi (500MHz) + IMT (700MHz)



Source: Telecom Advisory Services Analysis

4. ECONOMIC VALUE OF THE HYBRID ALTERNATIVE

4.1. The value of allocating 1200 MHz for indoor use and 500 MHz for outdoor use to unlicensed users

The allocation of 1200 MHz for indoor use and the lower part of the band for outdoor use for unlicensed use and the higher 700 MHz band outdoor for use by IMT (the “hybrid” option) introduces some technical limitations on the ability of IMT service providers to generate economic value. On the other hand, the erosion of value for unlicensed use in this alternative is primarily driven by the limitation imposed on outdoor usage, while some of the benefits for indoor access remain.

4.1.1. Enhanced broadband coverage and improved affordability

According to section 2.2.1., the 6 GHz allocation decision would have an impact in two areas of economic value of WISPs: (i) growing consumer surplus of existing customers as a result of faster broadband service, and (ii) increasing affordability and, consequently, penetration of broadband, which in turn impacts the GDP. However, under the 500 MHz allocation for outdoor use, it is estimated that 27.12% of total additional WISP connections will be affected by the limit put on the upper portion of the 6 GHz band in outdoor use. As detailed in Appendix A.2, by restricting access to the upper part of the 6 GHz band the first limiting factor is the ability to accommodate more users in the 350MHz (UNII-7) that can be allowed in possible outdoor operations for Wi-Fi. The 4 GHz and 5 GHz bands accommodate a maximum number of connections between 40 and 50; whereas, with the specification of the 802.11ax standard with the entire 6 GHz band, between 110 and 120 connections could be handled; that is, between 2.4 and 2.75 times more. Thus, if we take as an average scenario of Wi-Fi 6 deployment in a 102 RU configuration, for channel aggregation with the 2.4GHz, 5 GHz and 6 GHz bands, the restriction of the latter band ($\Delta\ Cap$), would represent a 27.12% lower deployment capacity of users that would have to be hosted in the lower bands This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation scenario.

To calculate the consumer surplus under this alternative, we multiply the total economic impact under the 1200 MHz scenario by the discount factor mentioned above (see table 4-1).

Table 4-1. Consumer surplus due to WISP user speed increase under 500 MHz outdoor restriction of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Impact under 1200 MHz alternative (US$ Billions)	$ 0.039	$ 0.076	$ 0.118	$ 0.164	$ 0.213	$ 0.265	$ 0.319	$ 0.361	$ 0.401	$ 0.442	$ 0.481
Discount factor	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%
Impact under 500 MHz alternative (US$ Billions)	$ 0.029	$ 0.056	$ 0.086	$ 0.120	$ 0.156	$ 0.193	$ 0.233	$ 0.263	$ 0.292	$ 0.322	$ 0.351

Sources: Telecom Advisory Services analysis

Based on the calculations of table 4-1, total 2024-2034 projected cumulative consumer surplus impact resulting from increasing broadband speed by reducing Wi-Fi congestion for WISP users amounts to US$ 2.10 billion.

In addition, the increase in affordability and broadband adoption yielded by WISPs benefitting from the 6GHz band results in a contribution to GDP is, again, discounted by 27.12% (see table 4-2)

Table 4-2. Brazil: GDP contribution of New WISP lines resulting from increased affordability under 500 MHz outdoor restriction of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in GDP under 1200 MHz (US$ Billion)	$ 2.315	$ 2.750	$ 3.168	$ 3.622	$ 4.186	$ 4.762	$ 5.352	$ 5.774	$ 6.206	$ 6.647	$ 7.098
Discount factor	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%	27.12%
Impact under 500 MHz alternative (US$ Billions)	$ 1.687	$ 2.004	$ 2.309	$ 2.640	$ 3.050	$ 3.471	$ 3.900	$ 4.208	$ 4.523	$ 4.844	$ 5.713

Sources: Telecom Advisory Services analysis.

The total cumulative impact on the GDP resulting from increased broadband penetration due to enhanced affordability and sharing is US$ 37.81 billion between 2024 and 2034.

4.1.2. Increased residential speed by reducing Wi-Fi congestion

As documented in section 2.2.2., the value to be generated by the increase in average wireless speed resulting from allocating spectrum in the 6 GHz band for all Brazilian broadband households relying on Wi-Fi connectivity in the premise translates into a contribution to the GDP and an increase in consumer surplus. Under the hybrid alternative, all benefits of the 1200 MHz allocation to unlicensed use in this case apply (see table 4-3).

Table 4-3. Brazil: Estimation of economic impact by reducing Wi-Fi congestion under 1200 MHz indoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(12) Impact speed on GDP	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%	0.73%
(13) Increase in GDP (%)	0.11%	0.17%	0.25%	0.35%	0.43%	0.51%	0.61%	0.68%	0.76%	0.85%	0.95%
(14) Brazil GDP Billion US$	$ 2,265	$ 2,362	$ 2,477	$ 2,632	$ 2,774	$ 2,924	$ 3,082	$ 3,249	$ 3,425	$ 3,610	$ 3,805
(15) Impact (US$ Billions)	$ 2.495	$ 3.974	$ 6.119	$ 9.218	$ 11.826	$ 14.988	$ 18.840	$ 22.187	$ 26.081	$ 30.658	$ 36.051

Sources: ANATEL; Cisco Virtual Networking Index

Thus, total GDP contribution of the 6 GHz band allocation between 2024 and 2034 will reach US$182.44 billion.

As in the case of the GDP analyzed above, the annual consumer surplus generated by faster Wi-Fi will also be influenced by the same trends that evolve after 2023. These trends will affect the annual contribution to faster speeds resulting from the 6 GHz 1200 MHz indoor allocation as follows (see Table 4-4).

Table 4-4. Consumer Surplus from reducing Wi-Fi congestion under 1200 MHz indoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) Average Download Speed	359.11	399.69	426.11	438.49	459.36	473.59	481.48	497.62	509.89	517.86	521.71
(2) New Average Download Speed	413.30	491.81	570.33	648.84	727.57	806.09	884.60	963.12	1041.85	1120.36	1198.88
(3) Demand for average download speed	93.00	94.46	95.33	95.72	96.35	96.77	96.99	97.44	97.77	97.98	98.08
(4) New Demand for average download speed	94.91	97.28	99.30	101.05	102.61	104.00	105.27	106.43	107.50	108.49	109.41
(5) Additional Monthly Consumer surplus	$1.91	$2.82	$3.97	$5.33	$6.26	$7.24	$8.28	$8.99	$9.72	$10.50	$11.32
(6) Additional Yearly Consumer Surplus	$22.95	$33.87	$47.60	$63.99	$75.10	$86.86	$99.34	$107.84	$116.69	$126.02	$135.88
(7) Fixed Broadband Connections (Millions)	50.144	53.024	55.821	58.336	58.619	58.891	59.163	59.437	59.713	59.989	60.267
(8) Impact (US$ Millions)	$1,151	$1,796	$2,657	$3,733	$4,402	$5,115	$5,877	$6,410	$6,968	$7,560	$8,189

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

In sum, total consumer surplus associated with the 6 GHz band between 2024 and 2034 will reach $53.86 billion.

4.1.3. Wide deployment of Internet of Things

As detailed in section 2.2.3., the enhanced deployment of IoT due to the 6 GHz allocation to unlicensed use will trigger two economic effects: (i) the generation of producer surplus (i.e. margins) of Brazilian eco-system suppliers in the IoT segment, and (ii) the spillover of IoT on the efficiency of Brazilian industries. As documented in appendix A.3, it is assumed that under the 500 MHz outdoor allocation of the hybrid alternative, a growing percentage of the revenues of the IoT equipment that operate outdoors will disappear. This has a negative impact on GDP contribution and producer surplus compared to the whole band allocation scenario.

Table 4-5. Producer Surplus of IoT deployment from 6 GHz unlicensed under the 500 MHz outdoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Revenue IoT Industries + Smart Cities	67.34%	69.02%	70.37%	71.50%	72.32%	73.69%	74.88%	75.91%	76.80%	77.57%	78.24%
Higher part of the band restricted (outdoor)	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact outdoor ecosystem	39.28%	40.26%	41.05%	41.71%	42.19%	42.99%	43.68%	44.28%	44.80%	45.25%	45.64%
Economic Impact	0.55	0.83	1.21	1.76	2.47	3.24	4.03	4.52	4.91	5.23	5.47

Source: CSI Insights; ABI Research; Telecom Advisory Services analysis

Based on the sum of annual values, the total cumulative value of producer surplus driven by sales of IoT equipment by Brazilian firms in Brazil under the 500 MHz outdoor allocation of the hybrid alternative between 2024 and 2034 amounts to US$ 34.22 billion.

In addition, IoT adoption contributes to GDP growth through the multiplicity of use cases that improve efficiency in processes such as preventive maintenance and production monitoring.

Table 4-6. Brazil: IoT Spillover under the 500 MHz outdoor allocation of the hybrid alternative (in US$ billion) (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Revenue IoT Industries + Smart Cities	67.34%	69.02%	70.37%	71.50%	72.32%	73.69%	74.88%	75.91%	76.80%	77.57%	78.24%
Higher part of the band restricted (outdoor)	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact outdoor ecosystem	39.28%	40.26%	41.05%	41.71%	42.19%	42.99%	43.68%	44.28%	44.80%	45.25%	45.64%
Economic Impact	1.86	1.83	1.94	2.11	2.10	2.41	2.79	2.40	2.80	3.20	3.61

Source: GSMA Intelligence; Statista Market Insights; Frontier Economics; Telecom Advisory Services analysis

According to the annual estimates, cumulative spillover impact of enhanced IoT deployment driven by the 500 MHz outdoor allocation of the hybrid alternative will reach US$ 27.04 billion between 2024 and 2034.

4.1.4. Reduction of enterprise wireless costs

As explained in section 2.2.4, the allocation of 6 GHz also has an economic effect in enterprise margins (or producer surplus), in terms of the savings from cellular usage implied by using unlicensed spectrum to handle traffic from high-capacity Wi-Fi devices rather than cellular networks.

Table 4-7. Brazil: Impact on enterprise wireless under the 1200 MHz indoor allocation of the hybrid alternative (2024-2034) (in ‘000’000 US$)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Traffic through 6 GHz Band	30.00%	37.50%	45.00%	52.50%	60.00%	67.50%	75.00%	80.00%	85.00%	90.00%	95.00%
Economic impact of 1200 MHz of the 6 GHz Band (US$ Billion)	$ 0.150	$ 0.265	$ 0.418	$ 0.612	$ 0.854	$ 1.152	$ 1.515	$ 1.898	$ 2.354	$ 2.899	$ 3.551

Source: Telecom Advisory Services analysis

The sum of the difference due to broader Wi-Fi traffic between 2024 and 2034 will reach US$ 15.67 billion.

4.1.5. Deployment of AR/VR solutions

As discussed in section 2.2.5., the development and diffusion of AR/VR applications in the production side of the economy is being driven by an ecosystem comprised of firms ranging from software development to hardware production and content creation. In this context, it is relevant to estimate whether a scenario of allocating only 500 MHz of the 6 GHz band for unlicensed use will have a diminishing effect on the producer surplus generated in Brazil because of the sales of AR/VR applications produced by domestic firms.

Under the 1200 MHz indoor and 500 MHz outdoor allocation of the hybrid alternative, it is estimated that the estimated value for the allocation of the whole band would be reduced by 58.33% for outdoor environments. This has a negative impact on GDP contribution and producer surplus as estimated under the whole band allocation scenario.

Table 4-8. Brazil: Producer surplus derived from AR/VR sales by Brazilian firms under the hybrid spectrum allocation (2024-2034) (in US$ billions)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Outdoor Usage	52.56%	52.09%	51.31%	51.10%	51.49%	52.16%	53.00%	53.00%	53.00%	53.00%	53.00%
Higher part of the band restricted	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact outdoor ecosystem	30.66%	30.39%	29.93%	29.81%	30.03%	30.43%	30.92%	30.92%	30.92%	30.92%	30.92%
Economic Impact (US$ Billion)	$ 0.07	$ 0.16	$ 0.30	$ 0.53	$ 0.83	$ 1.25	$ 1.79	$ 2.33	$ 2.95	$ 3.68	$ 4.53

Source: CSI Market Inc*: Industry Profitability ratios; ABI Research; Telecom Advisory Services analysis*

Based on this estimate, the total producer surplus value of AR/VR in Brazil (the direct impact) under the hybrid alternative between 2024 and 2034 is US$18.43 billion.

Furthermore, the adoption of AR/VR among Brazilian businesses will, in turn, have a spillover effect on productivity, thereby contributing to the growth of GDP (see table 4-9).

Table 4-9. Brazil: GDP Contribution resulting from AR/VR Spillovers hybrid spectrum allocation (2024-2034) (in US$ billion)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Outdoor Usage	52.56%	52.09%	51.31%	51.10%	51.49%	52.16%	53.00%	53.00%	53.00%	53.00%	53.00%
Higher part of the band	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%	58.33%
Impact (%)	30.66%	30.39%	29.93%	29.81%	30.03%	30.43%	30.92%	30.92%	30.92%	30.92%	30.92%
Impact (US$ Billion)	$ 0.87	$ 1.35	$ 2.05	$ 3.26	$ 5.30	$ 8.51	$ 12.86	$ 17.62	$ 22.34	$ 26.34	$ 28.86

Source: ABI Research; CSI Market Inc*: Industry Profitability ratios; Telecom Advisory Services analysis.*

Based on this estimate, the total spillover value of AR/VR in Brazil (the indirect impact) under the hybrid alternative between 2024 and 2034 will be US$ 129.37 billion.

4.1.6. Enhanced deployment of municipal Wi-Fi

As reported in section 2.2.6, municipal Wi-Fi can play a role in enhancing broadband service coverage by providing a free resource for consumers to gain access to the Internet. Along these lines, allocating spectrum in the 6 GHz band will increase the ability of municipal Wi-Fi to provide free service to unserved population or increase the speed of access for current users. These two effects translate into a contribution to GDP and an increase in consumer surplus. That said, according to Appendix A.5., under the 500 MHz outdoor allocation of the hybrid alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation scenario.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP[39], discounted by the limits imposed on outdoor traffic, yields the GDP impact of Municipal Wi-Fi (see table 4-10).

Table 4-10. Brazil: GDP impact of Municipal Wi-Fi networks under 500 MHz outdoor allocation of the hybrid alternative

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total GDP impact GDP under 1200 MHz alternative (US$ Billion)	$ 0.239	$ 0.315	$ 0.401	$ 0.509	$ 0.653	$ 0.826	$ 1.033	$ 1.251	$ 1.511	$ 1.820	$ 2.186
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
(15') Total impact in GDP under 500 MHz hybrid alternative (US$ Billion)	0.180	0.236	0.302	0.383	0.491	0.621	0.776	0.941	1.136	1.368	1.643

Source: IMF; ITU; Telecom Advisory Services analysis.

In sum, the cumulative contribution of GDP of the benefit accorded to municipal Wi-Fi networks by allocating spectrum in the 6 GHz band will reach US$ 8.077 billion between 2024 and 2034.

In addition to the contribution to GDP, municipal Wi-Fi networks with the capacity to leverage spectrum in 6 GHz can enhance their performance, providing faster broadband service, and thereby generating incremental consumer surplus. Again, relying on the discounting factor of 24.82% allows calculating the impact of municipal Wi-Fi on consumer surplus.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP, discounted by the limits imposed on outdoor traffic, yields the consumer surplus impact of Municipal Wi-Fi (see table 4-11).

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[39] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

Table 4-11. Brazil: Consumer surplus of households benefitting from municipal Wi-Fi under 500 MHz outdoor allocation of the hybrid alternative

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in consumer surplus under 1200 MHz alternative (US$ Billion)	$ 0.011	$ 0.019	$ 0.030	$ 0.044	$ 0.063	$ 0.087	$ 0.120	$ 0.157	$ 0.205	$ 0.266	$ 0.345
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
Total impact on consumer surplus under 500 MHz hybrid alternative (US$ Billion)	0.009	0.014	0.022	0.033	0.047	0.066	0.090	0.118	0.154	0.200	0.259

Source: IMF; ITU; Telecom Advisory Services analysis.

The cumulative consumer surplus to be generated by this effect amounts to US$ 1.013 million between 2024 and 2034.

4.1.7. Deployment of free Wi-Fi spots

Free Wi-Fi hot spots that benefit from 6 GHz spectrum will be capable of handling a higher number of devices, which in turn will contribute to broadband adoption. On the other hand, these sites will be able to deliver faster speed of service, which can be transferred to increasing consumer well-being. However, as in the case of municipal Wi-Fi, under the 500 MHz allocation of the hybrid alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on GDP contribution and consumer surplus as estimated under the whole band allocation alternative.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP[40], discounted by the limits imposed on outdoor traffic, yields the GDP impact of Freel Wi-Fi hotspots (see table 4-12).

Table 4-12. Brazil: GDP impact of Free Wi-Fi networks under 500 MHz outdoor allocation of the hybrid alternative

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total GDP impact GDP under 1200 MHz alternative (US$ Billion)	0.217	0.250	0.277	0.301	0.325	0.339	0.339	0.324	0.294	0.243	0.167
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
(15') Total impact in GDP under 500 MHz hybrid alternative (US$ Billion)	0.163	0.188	0.208	0.226	0.245	0.255	0.255	0.244	0.221	0.183	0.125

Source: IMF; ITU; Telecom Advisory Services analysis.

In sum, the cumulative contribution of GDP of the benefit accorded to Free Wi-Fi hotspots by allocating spectrum in the 6 GHz band will reach US$ 2.313 billion between 2024 and 2034.

[40] Katz, R., Callorda, F. and Jung, J. (2023). *The economic impact of broadband and digitization after the Covid-19 pandemic – Econometric Modelling*. Geneva: International Telecommunications Union

In addition to the contribution to GDP, free Wi-Fi hotspots with the capacity to leverage spectrum in 6 GHz can enhance their performance, providing faster broadband service, and thereby generating incremental consumer surplus. Again, relying on the discounting factor of 24.82% due to the 500 MHz outdoor allocation of the hybrid alternative allows calculating the impact of free Wi-Fi on consumer surplus.

The increase in broadband penetration multiplied by the coefficient of impact of fixed broadband on GDP, discounted by the limits imposed on outdoor traffic, yields the GDP impact of free Wi-Fi hotspots (see table 4-13).

Table 4-13. Brazil: Consumer surplus of households benefitting from Free Wi-Fi under 500 MHz outdoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Total impact in consumer surplus under 1200 MHz alternative (US$ Billion)	0.035	0.053	0.075	0.102	0.134	0.172	0.216	0.259	0.310	0.370	0.440
% Reduction of connections due to use of low part of 6GHz band	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
Total impact on consumer surplus under 500 MHz alternative (US$ Billion)	0.026	0.040	0.057	0.077	0.101	0.129	0.162	0.195	0.233	0.278	0.331

Source: IMF; ITU; Telecom Advisory Services analysis.

The cumulative consumer surplus to be generated by this effect amounts to US$ 1.629 billion between 2024 and 2034.

4.1.8. Aligning spectrum decision with other advanced economies

Under this scenario, partial alignment would occur with the decisions made by other advanced economies such as the United States, Canada, and South Korea. By extrapolating the trend through 2034 and applying the price difference to the AR/VR hardware and IoT hardware market, the following effect can be quantified (see table 4-14).

Table 4-14. Advantage of aligning the 6 GHz decision with the US model under 500 MHz outdoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
(1) AR-VR hardware market	$ 0.265	$ 0.391	$ 0.560	$ 0.722	$ 0.845	$ 0.950	$ 1.050	$ 1.167	$ 1.298	$ 1.444	$ 1.606
(2) IoT Hardware Market	$ 2.023	$ 2.172	$ 2.361	$ 2.456	$ 2.563	$ 2.510	$ 2.425	$ 2.315	$ 2.202	$ 2.086	$ 1.969
(3) Price reduction due to aligning spectrum decision	-1.61%	-1.54%	-1.47%	-1.40%	-1.34%	-1.28%	-1.22%	-1.16%	-1.10%	-1.04%	-0.98%
(4) Impact on producer surplus (US$B)	$ 0.037	$ 0.039	$ 0.043	$ 0.045	$ 0.046	$ 0.044	$ 0.042	$ 0.040	$ 0.038	$ 0.037	$ 0.035

Source: Telecom Advisory Services analysis based on ABI Research and Statista Market Insights

The cumulative producer surplus to be generated by this effect amounts to US$ 0.446 billion between 2024 and 2034.

4.1.9. Enhancing the capability for cellular off-loading

The key objective is to estimate the savings in capital investment as a result of an increase in traffic offloading with Wi-Fi benefits from the additional spectrum in the 6 GHz band, but more importantly, the ability to leverage 160 MHz within a single contiguous channel. However, under the 500 MHz allocation alternative, 24.82% of total users are affected in Internet access from open access points due to the restriction of the upper part of the 6 GHz band for outdoor use. This has a negative impact on the producer surplus as estimated under the whole band allocation scenario. From an estimated benefit between 2024 and 2034 if 1200 MHz were to be assigned to unlicensed use (producer surplus: US$ 3.24 billion), the benefit under a 500 MHz scenario would amount to US$ 2.44 billion.

4.1.10. Wi-Fi Devices and equipment

The development of a Brazilian industry focused on manufacturing Wi-Fi devices and equipment stimulated by the allocation of 6 GHz band would benefit from a producer surplus. Apart from the producer surplus generated by Wi-Fi devices and equipment in Brazil, there is also the creation of a consumer surplus, which represents the difference between what Brazilian consumers are willing to pay and what they actually spend. Under the 500 MHz allocation alternative, the proportional part of the incremental sales of unlicensed equipment for outdoor environments that could not be used would be reduced by 2.77% (see table 4-15).

Table 4-15. Producer surplus from Wi-Fi devices and equipment under 500 MHz outdoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Producer surplus 6 GHz devices under 1,200 MHz alternative	$370	$498	$627	$757	$890	$1,025	$1,163	$1,320	$1,498	$1,701	$1,931
Sales reduction due to outdoors	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%
Producer surplus 500 MHz hybrid alternative	$360	$485	$610	$736	$865	$996	$1,131	$1,284	$1,457	$1,654	$1,877

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative producer surplus to be generated by this effect amounts to US$11.454 billion between 2024 and 2034

Furthermore, we estimate the consumer surplus from Wi-Fi devices and equipment in Brazil between 2024 and 2034 (see table 4-16).

Table 4-16. Consumer surplus from Wi-Fi devices and equipment under 500 MHz outdoor allocation of the hybrid alternative (2024-2034)

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Consumer surplus 6 GHz devices under 1,200 MHz alternative	$784	$1,060	$1,344	$1,659	$1,975	$2,305	$2,651	$3,050	$3,508	$4,035	$4,641
Sales reduction due to outdoors	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%	2.77%
Producer surplus 500 MHz hybrid alternative	$762	$1,031	$1,307	$1,613	$1,920	$2,241	$2,578	$2,965	$3,411	$3,923	$4,513

Source: Telecom Advisory Services analysis based on Consumer Technology Association (2020) and CSI Market Inc.

The cumulative consumer surplus to be generated by this effect amounts to US$ 26.266 billion between 2024 and 2034.

4.1.11. A compilation of economic value of the hybrid alternative for unlicensed use

So far, the analysis provided the cumulative economic impact of allocating full indoor and 500MHz outdoor in the 6 GHz band. Based on the aggregated results, the allocation of full indoor and 500MHz outdoor for 6 GHz for unlicensed use in Brazil will generate cumulative economic value between 2024 and 2034 reaching US$387.04 billion in additional GDP, US$82.65 in producer surplus (which includes both margins for Brazilian technology suppliers to meet local demand and savings from enterprise wireless use and capital from telecommunications carriers engaged in 5G deployment), and US$84.87 billion in consumer surplus (benefits to consumers in terms of lower cost per Mbps and faster speed) (see table 4-17).

Table 4-17. Brazil: Economic Value of Allocating 1200 MHz for indoor use and 500 MHz for outdoor use by unlicensed users (2024-2034) (in US$ billion)

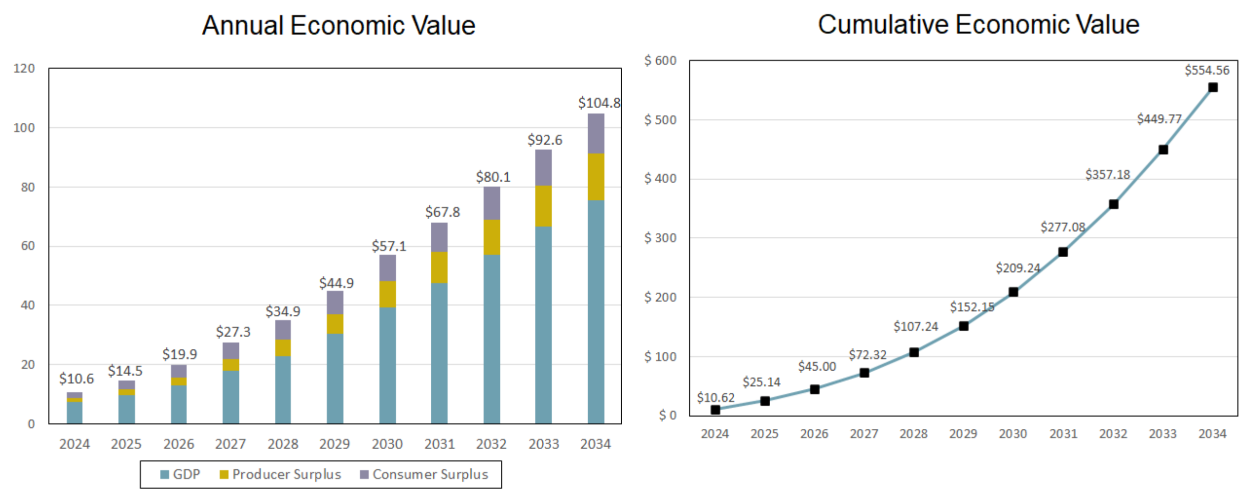
Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in WISP sector **$ 37.81**		Faster speed of access for WISP subscribers **$ 2.10**
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi **$ 182.44**		Consumer surplus from increasing speed **$ 53.86**
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the Brazilian economy (e.g. automotive, food processing, logistics) **$ 27.04**	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment **$ 34.22**	

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications **$ 15.67**	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy **$ 129.37**	Margins of ecosystem firms involved in AR/VR deployment **$ 18.43**	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption **$ 8.08**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.01**
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption **$ 2.31**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.63**
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices) **$0.45**	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots **$ 2.44**	
Wi-Fi Devices and equipment		Margin of firms due to the sales of Wi-Fi Devices and Equipment **$ 11.45**	Consumer surplus from sales of Wi-Fi Devices and Equipment **$ 26.27**
TOTAL	**$ 387.04**	**$ 82.65**	**$ 84.87**

Source: Telecom Advisory Services analysis

The total economic value increases over time with significant acceleration towards the end of the period due to the leverage capability of 6 GHz (see graphic 4-1).

Graphic 4-1. Brazil: Economic value of allocating 1200 MHz for indoor use and 500 MHz for outdoor use by unlicensed users in the 6 GHz band



Source: Telecom Advisory Services analysis

4.2. Value of the upper 700 MHz (Only Outdoors) for IMT

Part of the negative economic impact of limiting access of the 6 GHz band for unlicensed use is mitigated by the benefits resulting from allocating 700 MHz only outdoors to IMT. These benefits can also be categorized in terms of GDP contribution, producer surplus, and consumer surplus.

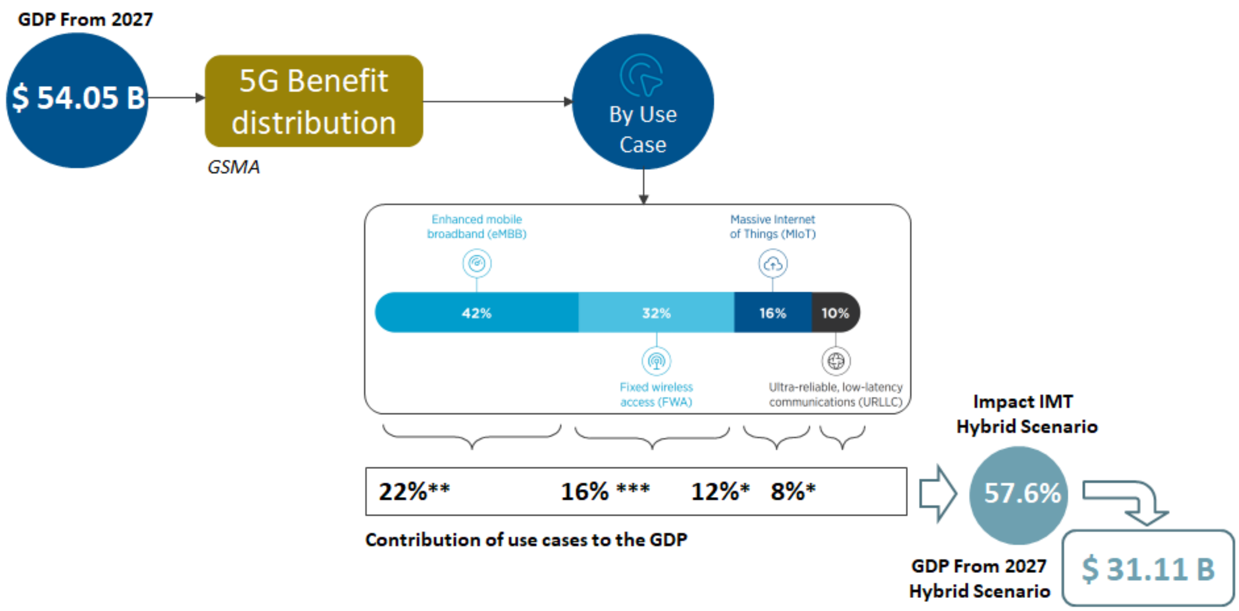
4.2.1. GDP contribution

In this section, it is important to consider that the upper part of the 6 GHz band could experience degradation in indoor environments due to the use cases or applications that 5G might use in these settings because of the sharing with Wi-Fi (Hybrid Scenario).

GSMA (2022a), in its model of the impact of 5G on GDP in Brazil, validates its calculation through three approaches: (i) By industry, (ii) By use case; and (iii) By band. For the analysis of use cases, enhanced mobile broadband (eMBB) contributes 42%; while Fixed Wireless Access (FWA) contributes 32%, Massive Internet of Things (MIoT) 16%; and Ultra-reliable, low-latency communications (URLLC) 10%.

Taking into account that several of the use cases would suffer deterioration in their signal due to indoor uses in conjunction with Wi-Fi, there would be a deterioration of 22% for eMBB (caused by impact in the AR/VR sector of 47.53%), 16% for FWA (due to half of the mobile users indoors who could suffer interference), 12% for IoT, and 8% for URLLC (both due to indoor IoT uses of 24.89%) (see Figure 4-1).

Figure 4-1. Impact of 5G on GDP for hybrid scenario



Source: Telecom Advisory Services based on GSMA

** Reduction caused by indoor use since 24.89% of IoT applications are indoors (Source: TAS analysis based on Statista data for Brazil)*

*** Reduction caused by AR/VR since 47.53% of applications are indoors (Source: TAS analysis based on ABI Research for LATAM)*

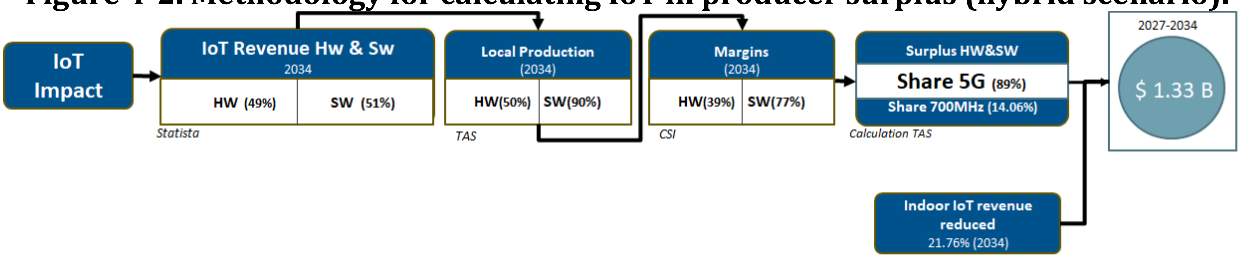
**** Only 50% of the impact from Fixed Wireless Access (FWA) will be accounted for, as more than half of its usage occurs indoors*

In this manner, 5G is projected to have an impact on the Brazilian GDP amounting to approximately US$ 9.05 billion annually by the year 2034. Considering the entirety of the period under analysis (2027-2034), the cumulative impact on GDP is estimated to reach US$ 31.11 billion.

4.2.2. Producer surplus

Similarly to the aforementioned sources of value, in the case of sharing the spectrum in outdoor environments between 5G and Wi-Fi, primarily, there could exist interference for the mobile sector within indoor areas of the upper part of the 6GHz band. Consequently, the economic effect attributed to the IoT could be proportionally reduced based on the percentage of revenue in the IoT sector that applies to indoor environments (21.76% by the year 2034). In this regard, the producer surplus from the use of IoT devices, with this restriction on sharing in indoor settings, could be reduced to US$ 1.33 billion over the entire period (see Figure 4-2).

Figure 4-2. Methodology for calculating IoT in producer surplus (hybrid scenario).

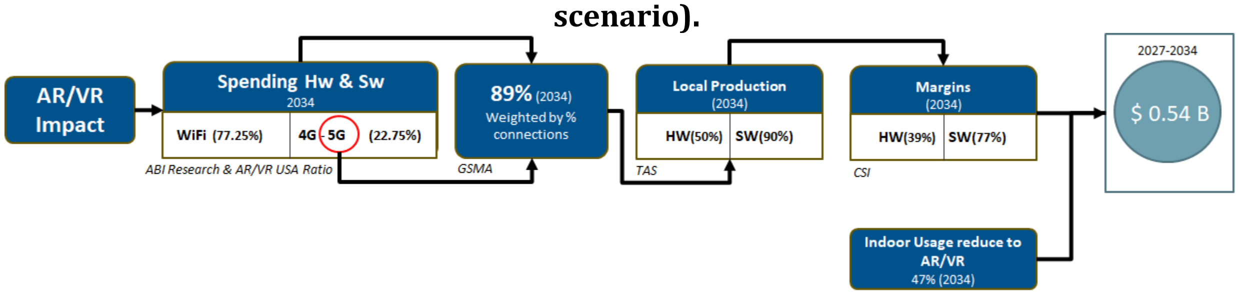


Source: Telecom Advisory Services based on Statista Market Insights and CSI

In the case of spectrum sharing for outdoor environments between 5G and Wi-Fi, primarily, interference for 5G devices used indoors, which might operate on the 6GHz band, could occur. Consequently, the economic impact attributed to AR/VR will be diminished proportionally, based on the percentage of active users across different use cases implemented for indoor environments (47% by the year 2034).

In this regard, the producer surplus from the use of AR/VR devices, with this restriction on indoor spectrum sharing, could be reduced to US$ 0.54 billion over the entire period (see Figure 4-3).

Figure 4-3. Methodology for calculating AR/VR in producer surplus (hybrid scenario).



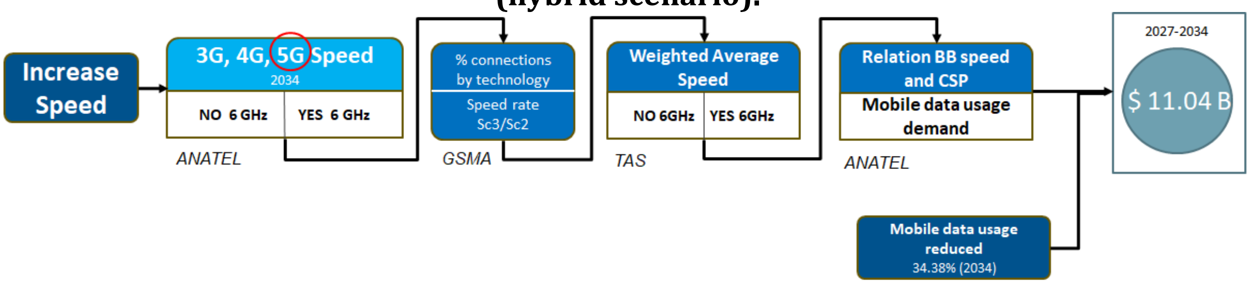
Source: Telecom Advisory Services based on ABI Research

4.2.3. Consumer surplus

In a shared scenario in indoor environments between 5G and Wi-Fi, the economic effect attributed to the increase in mobile speed could be reduced proportionally, depending on the percentage of a user's mobile data usability when using the service at home, where, of course, the largest percentage of usage is assigned to internet access through Wi-Fi.

In this regard, the consumer surplus from the speed improvement, with this restriction for sharing in indoor environments, will amount to US$ 11.04 billion over the entire period (see Figure 4-4).

Figure 4-4. Methodology for calculating consumer surplus due to speed change (hybrid scenario).

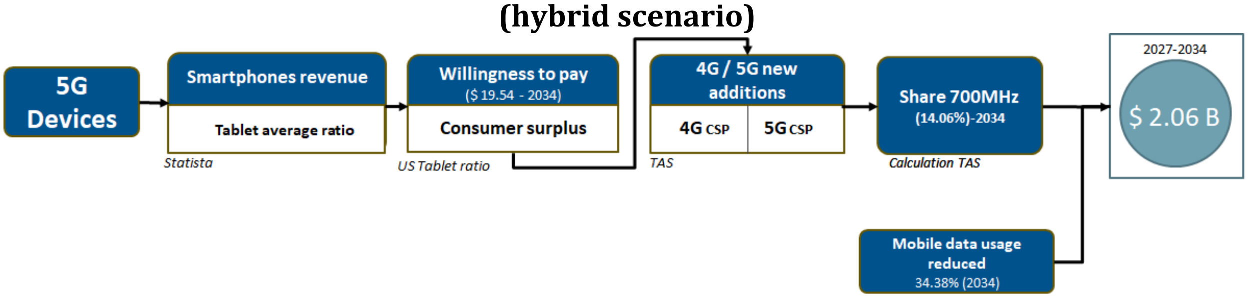


Source: Telecom Advisory Services analysis based on ANATEL and GSMA

In the shared scenario of outdoor environments between 5G and Wi-Fi, the economic effect associated with the purchase of smart devices could be reduced, proportionally, based on the percentage of mobile data usability of a user when utilizing the service at home (34.38% by the year 2034), where, of course, the larger percentage of usage is allocated to internet access through Wi-Fi.

In this context, the consumer surplus from purchasing smartphones, with this restriction for sharing in indoor environments, will amount to US$ 2.06 billion over the entire period (see Figure 4-5).

Figure 4-5. Methodology for calculating residential equipment in consumer surplus (hybrid scenario)



Source: Telecom Advisory Services based on Statista Market Insights

4.2.4 Mid-band auction proceeds

Finally, under the alternative where IMT actors are assigned 700 MHz of the 6 GHz band solely for outdoor environments, it is reasonable to assume that a potential auction could generate additional revenue. We have estimated this amount based on auction 3.5 band(see Table 4-17).

Table 4-17. Estimate of 700 MHz (only outdoors) in the 6GHz auction proceeds

Variable	Spectrum amount	Total proceeds (US$)	Amount per MHz (US$)
3.5 GHz Auction (2021)	300 MHz	$ 250.50	$ 0.84
Investment commitmentds		$ 4,731.90	$ 15.77
Total 3.5 GHz auction	300 MHz	$ 4,982.40	$ 16.61
Extrapolation to 700 MHz in 6 GHz	700 MHz*	$ 6,692.33	$ 9.56

** IMT value diminished because is only for outdoors*
Source: Telecom Advisory Services analysis.

Under the best scenario, one can assume that auction proceeds will be reinvested in network deployment, which would result in a total value of US$ 6.69 billion (primarily in commitments). Considering this value in the final economic impact may carry the risk of double counting with the impact on GDP, as if the spectrum payment occurs in commitments, that would already be accounted for in the impact on the 5G GDP. In the event it occurs as a transfer to the government, it is a monetary transfer, without impact on the economic aggregate.

4.3. A compilation of economic value of the hybrid alternative

So far, the analysis provided the cumulative economic impact of allocating full indoor and 500MHz outdoor in the 6 GHz band. Based on the aggregated results, the allocation of full indoor and 500MHz outdoor for 6 GHz for unlicensed use in Brazil will generate cumulative economic value between 2024 and 2034 reaching US$387.04 billion in additional GDP, US$82.65 in producer surplus (which includes both margins for Brazilian technology suppliers to meet local demand and savings from enterprise wireless use and capital from telecommunications carriers engaged in 5G deployment), and US$84.87 billion in consumer surplus (benefits to consumers in terms of lower cost per Mbps and faster speed) (see table 4-18).

Table 4-18. Brazil: Economic Value of Allocating 1200 MHz for indoor use and 500 MHz for outdoor use by unlicensed users (2024-2034) (in US$ billion)

Source of Value	GDP contribution	Producer surplus	Consumer surplus
Enhance coverage and improve affordability	Improve affordability associated with broadband provision and increasing access sharing in WISP sector **$ 37.81**		Faster speed of access for WISP subscribers **$ 2.10**
Increased speed by reducing Wi-Fi congestion	Benefits of eliminating router bottleneck in high-speed connections by increasing speed of in-door Wi-Fi **$ 182.44**		Consumer surplus from increasing speed **$ 53.86**
Wide deployment of Internet of Things	Spillovers of IoT deployment on productivity on key sectors of the	Margins of ecosystem firms (Hardware, software, services) involved in IoT deployment	

Source of Value	GDP contribution	Producer surplus	Consumer surplus
	Brazilian economy (e.g. automotive, food processing, logistics) **$ 27.04**	**$ 34.22**	
Reduction of enterprise wireless costs		Cost reduction of enterprise use of wireless communications **$ 15.67**	
Deployment of AR/VR solutions	Spillovers of AR/VR deployment on the Brazilian economy **$ 129.37**	Margins of ecosystem firms involved in AR/VR deployment **$ 18.43**	
Enhanced deployment of municipal Wi-Fi	Increase in GDP due to enhanced broadband adoption **$ 8.08**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.01**
Deployment of Free Wi-Fi Hot Spots	Increase in GDP due to enhanced broadband adoption **$ 2.31**		Consumer surplus from faster data download rate as enabled by faster broadband **$ 1.63**
Aligning spectrum decision with other advanced economies	Potential opportunity of creating a Wi-Fi equipment manufacturing sector	Benefits of economies of scale of aligning Brazil with US (lower equipment prices) **$0.45**	
Enhancing the capability for cellular off-loading		CAPEX reduction derived from offloading wideband wireless traffic to carrier grade Wi-Fi hot spots **$ 2.44**	
Wi-Fi Devices and equipment		Margin of firms due to the sales of Wi-Fi Devices and Equipment **$ 11.45**	Consumer surplus from sales of Wi-Fi Devices and Equipment **$ 26.27**
TOTAL	**$ 387.04**	**$ 82.65**	**$ 84.87**

Source: Telecom Advisory Services analysis

Considering the economic value for IMT, amounts to US$ 31.11 B in GDP contribution, US$ 1.87 B in producer surplus, and US$ 13.10 B in surplus to the Brazilian consumers (see table 4-19).

Table 4-19. Economic value of allocating 700 MHz (only outdoors) in the 6 GHz band for 5G (2024-2034) (in US$ billions)

Source of Value	GDP contribution	Producer surplus	Consumer surplus
I. Enhance coverage and improve affordability	$31.11 (GSMA)		
2. Increased speed by reducing Wi-Fi congestion			$ 11.04
3. Wide deployment of Internet of Things		$ 1.33	
4. Reduction of enterprise wireless costs			
5. Deployment of AR/VR solutions		$ 0.54	
6. Enhanced deployment of municipal Wi-Fi			
7. Deployment of Free Wi-Fi Hot Spots			
8. Aligning spectrum decision with other advanced economies			
9. Enhancing the capability for cellular off-loading			

10. Wi-Fi Devices and equipment		[redacted]	$ 2.06
TOTAL	**$ 31.11**	**$ 1.87**	**$ 13.10**

Source: Telecom Advisory Services analysis

An additional benefit exists due to the auction potential of the 700 MHz spectrum, which is estimated at US$ 6.69 billion (primarily in commitments).

So, the total value of the economic impact of the partial allocation of the 6GHz band for IMT (GDP, producer and consumer surplus) has a significant quantitative element: (i) in this scenario (700 MHz - IMT outdoor at the upper part of 6 GHz) shared with the complete allocation for WiFi (1200 MHz indoor - 700MHz outdoor); in other words, a hybrid scenario, is 11.88% lower than the impact generated by the total allocation to WiFi (1200MHz) (see Table 4-20).

Table 4-20. Analysis of the allocation of the 6GHz band – IMT (700 MHz – Outdoors)

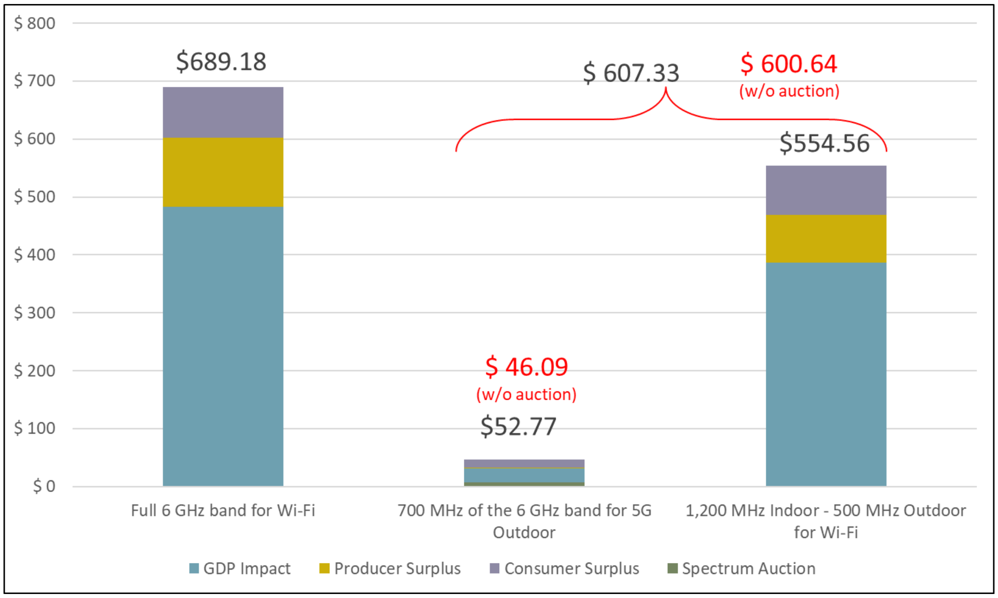
Scenario	GDP Impact	Producer Surplus	Consumer Surplus	Spectrum Auction	TOTAL
Full 6 GHz band for Wi-Fi	$482.77	$119.14	$87.27	$0.00	$689.18
700 MHz of the 6 GHz band for 5G Outdoor (E2)	$31.11	$1.87	$13.10	$6.69	$52.77
1,200 MHz Indoor - 500 MHz Outdoor for Wi-Fi	$387.04	$82.65	$84.87	$0.00	$554.56

Source: Telecom Advisory Services Analysis

In comparison with the scenarios proposed for the allocation of the 6 GHz band for WiFi, the following considerations are made:

- The difference ($134.62 billion) between the total allocation ($689.18 billion) and partial allocation ($554.56 billion) of the 6 GHz band for Wi-Fi is greater than the expected effects of partial allocation for 5G in a hybrid scenario ($52.78 billion) (see Figure 4-6)
- While in this comparison there is a minimal difference, it's important to consider that the costs of spectrum reassignment have not been taken into account. Additionally, there could be IMT interference effects on WiFi in indoor environments, which would reduce the economic valuation of the WiFi band

Figure 4-6. Comparison between 6GHz band allocation – hybrid alternative

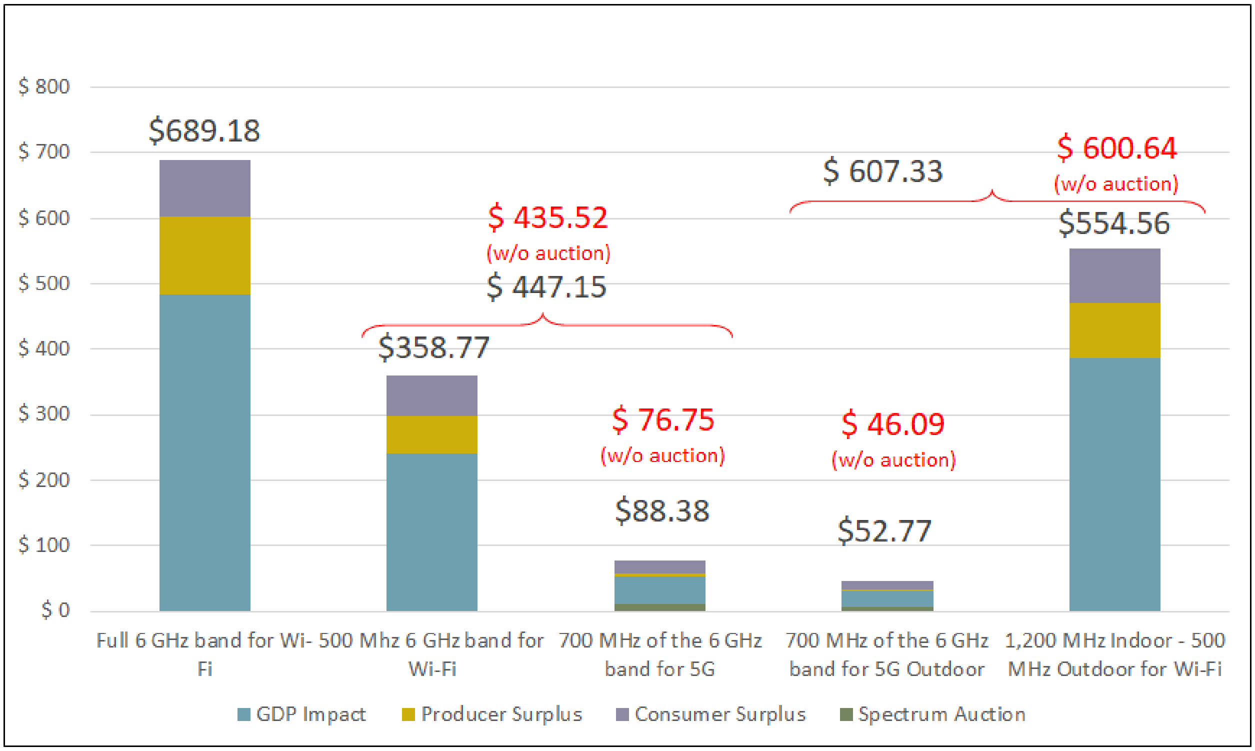


Source: Telecom Advisory Services Analysis

5. COMPARISON OF ECONOMIC VALUE OF ALL 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 restricted radiation equipment (see Graphic 5-1).

Graphic 5-1. Comparative economic value of the three regulatory alternatives



Source: Telecom Advisory Services analysis

As indicated in graphic 5-1, values for the IMT allocation are provided with and without spectrum auction estimated proceeds. Yet, even if those are included in the total value estimate, the full allocation to restricted radiation equipment use is US$242.03 billion higher than the partial allocation and US$81.85 billion than the "hybrid" alternative.

Furthermore, considering the current availability of 6 GHz certified devices, relative to the three-year lag of IMT in launching service in the band, Wi-Fi has the advantage of generating immediate economic impact and presents larger potential to increase coverage in rural areas These advantages occur, even without considering the costs to IMT generated by spectrum refarming, such as having to relocate incumbent 6 GHz fixed service links to other spectrum bands.

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TECHNICAL APPENDICES

This document explains the assumptions and methodology related to the economic impact of the partial or complete allocation of the 6 GHz band for the application of the WiFi 6 standard. It is composed of two parts: (i) the technical justification of the value of the saturation speed due to the partial or complete restriction of the 6 GHz band; and, (ii) the analysis of the values that have a direct impact on the economy due to the restriction of the 6 GHz band on each of the areas and use cases.

The first part covers two areas: (i) saturation rate due to the complete restriction of the 6 GHz band; and, (ii) saturation rate due to the partial restriction of the upper part of the 6 GHz band. In the second part, points 2 through 13, the percentage impact of the partial restriction of the 6 GHz band for the use of the WiFi 6 standard in various sectors that are linked to GDP, consumer surplus and producer surplus is estimated.

A.1. Fixed broadband speed threshold without the 6 GHz band

a) General explanation

In the economic impact analysis due to access to the 6 GHz band in Brazil, it is established that **those households that purchase** fixed broadband plans **higher than 150 Mbps could experience** network performance **saturation problems** as a result of a **limited spectrum** CPE, since the router only relies on the 2.4 GHz and 5 GHz bands.

In this regard, it is important to consider that the performance of WiFi or wireless technology is compromised by environmental factors such as congestion, noise and interference. In this context, WiFi 6 solves both performance and coverage challenges. In addition, the technology introduces a combination of features including OFDMA and 1024-QAM peak modulation to improve spectral efficiency, increase speed while supporting many devices in a congested area.

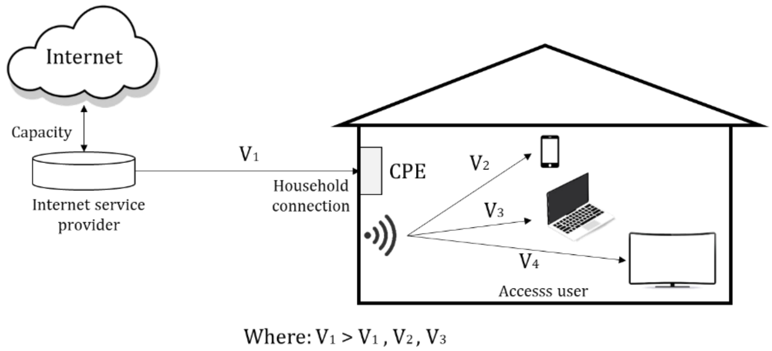
To better understand the advantages generated by WiFi 6 and its operation over the 6 GHz band, with a wider radio spectrum, we must necessarily go back to the analysis of two fundamental aspects: (i) the speed limitations due to the transmission medium; and, (ii) the operation of previous standards such as 802.11n (WiFi 4) and 802.11ac (WiFi 5), as well as their operation challenges over the 2.4 GHz and 5 GHz bands.

In the first place, the elements that play a crucial role in speed are the connection[41] between the Internet Service Provider (ISP) and the home; and the access mechanism (wired or wireless) by which a user connects[42] to the service. In other words, the key is linked to the characteristics of the transmission medium; and, therefore, a user's access speed to the

[41] We will call **connection** the access that a household has to the Internet; that is, the service contracted by a customer to an Internet Service Provider (ISP).
[42] We will call a **user** the internal customer of a household who can access the Internet through a wired or wireless medium.

service can never be higher than the effective speed of the connection at home (see Figure 1).

Figure 1. Relationship between connection speed and user access



Source: Telecom Advisory Services.

In that sense, access to the wireless medium, within WiFi technology, will determine the maximum speed that can be achieved by a user. Currently, according to Quotient Associates (WiFi Alliance, 2017), WiFi 4 (802.11n) and WiFi 5 (802.11ac) technologies are the most adopted in the world; while, the most used bands for the development of these standards are 2.4 GHz and 5 GHz. Typical channelizations and theoretical maximum speeds for these technologies indicate that 80% of the traffic is generated by devices operating in the 2.4 GHz band[43] (See Table 1). In other words, the maximum speed achieved for a 40 MHz channel could reach 150 Mbps.

Table 1. Relationship between speed and bandwidth in the most widely used WiFi 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 WiFi Alliance (2017). [44]

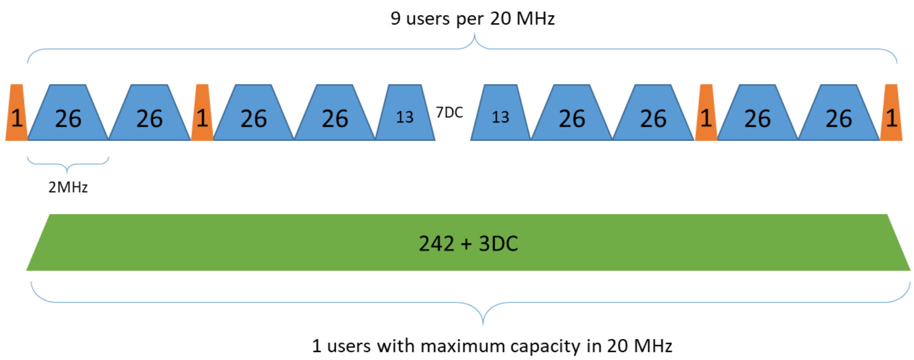
Taking into consideration that these technologies have been presenting challenges in terms of saturation due to the large amount of equipment and devices that have been deployed, as well as the restriction of the maximum available bandwidth, 802.11ax technology, known as WiFi 6, has begun to offer a solution to the challenges generated by previous technologies. The main features of WiFi 6 can be summarized in five aspects: (i) increased channel aggregation[45] due to increased bandwidth at the 6 GHz frequency, (ii) channel splitting by

[43] Source: Gehlhaus, D et. al (2018) www.rand.org/t/RR2720
[44] Source: WiFi Alliance.(2017), "Wi-Fi Spectrum Needs Study." WiFi Alliance, Table 2-1.
[45] The maximum bandwidth for WiFi 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.

multiple access of multiple users by orthogonal frequency division[46] (OFDMA), (iii) transmission link adaptation through maximum 1024-QAM modulation[47] , (iv) guard or guard interval to avoid information overlap[48] ; and, (v) transmission of multiple simultaneous information streams over the same channel to increase bandwidth[49] .

In this context, if we consider a saturation scenario for a single user per channel, occupying **802.11ax** technology **(WiFi 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 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. Thus, the **maximum speed reached** in this scenario can be **148.28 Mbps** (see Eq.1) for 1SS (*spatial stream*).

Figure 2. Channelization for WiFi 6 in a bandwidth of 20 MHz



Source: Telecom Advisory Services adapted from CISCO[50]

$$(Ec.1) \quad V_{max} = \frac{BPS.CE}{TT} * RU * SS = \frac{10\ bps.\frac{5}{6}}{13.6x10^{-6}\ seg} * (242) * 1 = 148.28\ Mbps$$

[46] 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.

[47] WiFi 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.

[48] 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 12.8us, and its guard interval corresponds to 0.8us, i.e. a total of 13.6us.

[49] 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.

[50] Source: CISCO. https://blogs.cisco.com/networking/wi-fi-6-ofdma-resource-unit-ru-allocations-and-mappings

With this, it could be approximated 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.**

On the other hand, it is important to recognize that 802.11 standards previously developed on the 2.4 GHz and 5 GHz bands have lower capacities, and that more and more resources will be used by devices. Thus, according to the report *Wi-Fi Spectrum Needs Study* (WiFi Alliance, 2017), it describes the largest worldwide adoption of 802.11n, followed by 802.11ac; while, it is expected that by 2025, 802.11ax (WiFi 6) will be generalized. In this regard, although 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 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.

b) Explanation of average speeds in Brazil as reported by ANATEL

The Brazilian regulator, ANATEL, has issued in 2019, Resolution No. 717, dated December 23, 2019[51] , by which it approves the Regulation on Quality of Telecommunications Services. In said regulation, the INF4 indicator, which corresponds to download and upload speed, is included within the set of informative indicators (IQS). This expresses the network capacity for data transfer per second, and its measurement is composed of aggregates at the level of operator, municipality and transmission technology[52]. However, these values do not necessarily have to coincide with the theoretical maximum value that a user can reach in a high traffic environment with a minimum operating channel of 20 MHz; rather, it also depends on other parameters such as the speed of the connection, the number of devices in the environment, and the resources used by the applications being executed.

Thus, if we take as an example the download speeds of six (6) operators in the municipality of Brasilia, both for the 2.4 GHz and 5 GHz bands, the average upload and download speed in that locality is 22.85 Mbps and 201.87 Mbps, respectively (see Figure 3). On the other hand, assuming that 60% of traffic is transferred over the 5 GHz band and 40% over the 2.4 GHz band[53], the overall average download speed in the unlicensed spectrum bands for that municipality would be 130.26 Mbps, which is even lower than the theoretical 150 Mbps that could be achieved with 802.11ax.

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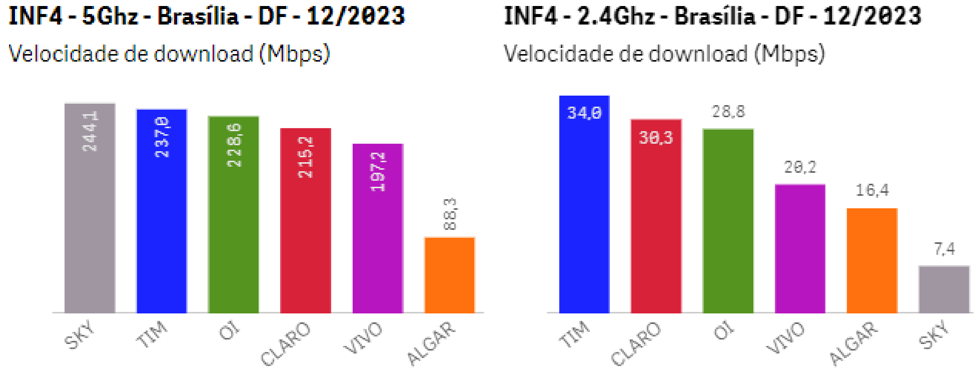
[51] Source: ANATEL. https://informacoes.anatel.gov.br/legislacao/resolucoes/2019/1371-resolucao-717
[52] Source: ANATEL Statistics. https://informacoes.anatel.gov.br/paineis/qualidade/velocidade-banda-larga-fixa
[53] According to the study (Gehlhaus, D et al, 2018), as of 2017, traffic resolution in the 2.4 GHz band was approximately 80%. In that sense, and taking into account that current usage projections are mostly for the 5 GHz band, the traffic usage ratio of 60% for 5 GHz and 40% for 2.4 GHz will be used.

Figure 3. Download speed by operator and unlicensed frequency band in the municipality of Brasília



Source: ANATEL[2] *.*

c) Saturation rate with a potential restriction of the upper part of the 6 GHz band

While we recognize that the total restriction to the 6 GHz band could establish a saturation speed accessed by users at 150 Mbps, it is important to understand that the use of the lower part of the 6 GHz band (500 MHz) would increase the theoretical maximum speed that a user could access. Still, a constraint should exist if the number of resource units (RU) used increases.

Thus, for an average access scenario, in a 102 RU configuration, for the aggregation of channels with the 2.4 GHz, 5 GHz and 6 GHz bands, a value close to 86 connections could be achieved. Also, if it is considered that the maximum allowed modulation can be 1024-QAM, then **the maximum speed**, derived from equation 1, for 8 *spatial stream*, **could be 500 Mbps** (see Eq. 2).

$$(Ec. 2) \quad V_{max} = \frac{BPS.CE}{TT} * RU * SS = \frac{10\ bps.\frac{5}{6}}{13.6x10^{-6}\ seg} * (102) * 8 = 500\ Mbps$$

It is also important to recognize that the maximum theoretical speed that could be achieved with access to the entire 6 GHz band, under the same modulation and data flow conditions, but with the maximum size of resource units (1960) would be 1.2 Gbps.

A.2. Reduction of impact on WISP performance, if outdoor use of the 6 GHz band is restricted

a) Introduction

ANATEL is currently in the **public consultation stage for the revision of** the total bandwidth identified[54] for the use of 802.11ax technology, commonly known as **WiFi 6**. **One of the possibilities** for the revision is the coexistence with IMT systems across the range in the use of the 6 GHz band, **thus allowing only the use of 500 MHz of the total low band for WiFi 6 outdoors**, which would obviously restrict the use of the high band of 6 GHz in *outdoor* environments to 5G technology.

In principle, at the technical level, there are at least two specifications that would make it impossible to deploy IMT in the 6 GHz band or to coexist with systems using WiFi 6 technology:

- IMT systems cannot coexist with existing operations in this frequency range; since they operate at power levels that make it difficult for them to share the spectrum; therefore, it is difficult for them to avoid or tolerate interference from existing operations in the 6 GHz band[55] ; and,
- There is a need to ensure that unlicensed spectrum bandwidth does not become a bottleneck for broadband connectivity; that is, that access to the 6.425-7.125 GHz spectrum can support the ever-increasing demands for ultra-low data throughput rates and latencies[15] . Currently, the adoption of technology in the 2.4 GHz and 5 GHz bands is dynamically limited[56] by the access of other devices that have channel priority (DFS); and for which *Transmit Power Control* (TPC) and *Automated Frequency Coordination* (AFC) technologies.

On the other hand, from a commercial point of view, it must be understood that the competition of technologies in vertical spectrum markets is at stake; that is, the use of private 5G for enterprise solutions where WiFi 6 and 6E developments tend to occupy wide channels, 80MHz and 160 MHz, which are channeled in the 6 GHz band. Also, another commercial aspect at stake is the competition in *outdoor* solutions for good capacity and low coverage *backhaul* links that could be used in LPWAN or WNAN type network configurations for device connectivity solutions in digital cities and industrial environments.

It should be noted that the 802.11ax standard operates in the 2.4 GHz, 5 GHz and 6 GHz bands. This specification defines an improvement in the average throughput per user by a factor of four times[57] . In this sense, it is important to summarize the most important characteristics of the application of the technology in each frequency band (see Table 2), in order to analyze the possible effects that the standard may have in the case of restricting its use, mainly outdoors.

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[54] Source: ANATEL, https://sei.anatel.gov.br/sei/modulos/pesquisa/md_pesq_documento_consulta_externa.php?eEP-wqk1skrd8hSlk5Z3rN4EVg9uLJqrLYJw_9INcO7uvjUt3vSOwT_4Z5fukj9yIzPErY4KWH5cpE9W_9hcTZkCG-vLPIdpXyuhgMG-L9M-uBLoSdAAXO0clb3SIt1i

[55] Source: WiFi Alliance, https://www.wi-fi.org/beacon/the-beacon/special-feature-the-road-to-wrc-23-important-decision-making-that-will-affect-the

[56] Certain channels are dynamically limited by *Dynamic Frequency Selection* (DFS) which are channels specified in multiple countries to prioritize military radars, satellite communication, weather radars, among others.

[57] Source: National Instruments, https://www.ni.com/en/solutions/semiconductor/wireless-connectivity-test/introduction-to-802-11ax-high-efficiency-wireless.html

Table 2. Comparison of the use of WiFi 6 on the frequency bands.

Parameter		2.4 GHz (60MHz)		5 GHz (500MHz)			6 GHz (1200 MHz)		
Frequency band		(B1) 2472-2412: 60MHz (ISM)		(B1) 5170-5330: 160MHz (UNII-1-2) (B2) 5490-5730: 240MHz (UNII-2Ex) (B3) 5735-5835: 100MHz (UNII-3)			(B1) 5925-6425: 500MHz (UNII-5) (B2) 6425-6525: 100MHz (UNII-6) (B3) 6525-6875: 350MHz (UNII-7) (B4) 6875-7125: 250MHz (UNII-8)		
Indoor (I) / Outdoor (E) Use		(B1) I - E		(B1) I (B2$_E$) I - E (B3$_E$) I - E			(B1$_E$) I - E (B2) I (B3$_E$) I - E (B3) I		
Number of channels in the WiFi standard6		**20MHz**	**40MHz**	**20MHz**	**80MHz**	**160 MHz**	**20MHz**	**80MHz**	**160 MHz**
		(B1) 3	(B1) 1	(B1) 8 (B2$_E$) 12 (B3$_E$) 5	(B1) 2 (B2$_E$) 3 (B3$_E$) 1	(B1) 1 (B2$_E$) 1 (B3$_E$) 0	(B1$_E$) 24 (B2) 5 (B3$_E$) 17.5 (B3) 12.5	(B1$_E$) 6 (B2) 1.25 (B3$_E$) 4.25 (B3) 2.5	(B1$_E$) 3 (B2) 0.5 (B3$_E$) 2.25 (B3$_E$) 1.25
	TOTAL connections	**3**	**1**	**25**	**6**	**2**	**59**	**14**	**7**
	TOTAL ext. conn.	**3**	**1**	**17**	**4**	**1**	**41**	**10**	**5**
Resource Units (RU) per bandwidth	**26 UK**	9	18	9	37	74	9	37	74
	52 UK	4	8	4	16	32	4	16	32
	102 UK	2	4	2	8	16	2	8	16
	242 UK	1	2	1	4	8	1	4	8
	484 UK	-	1	-	2	4	-	2	4
	980 UK	-	-	-	1	2	-	1	2
	1960 UK	-	-	-	-	1	-	-	1
Maximum theoretical speed (Mbps) per bandwidth in 1SS and 8SS	**26 UK**	15.93 127.45	15.93 127.45	15.93 127.45	15.93 127.45	15.93 127.45	15.93 127.45	15.93 127.45	15.93 127.45
	52 UK	31.86 254.90	31.86 254.90	31.86 254.90	31.86 254.90	31.86 254.90	31.86 254.90	31.86 254.90	31.86 254.90
	102 UK	62.50 500.00	62.50 500.00	62.50 500.00	62.50 500.00	62.50 500.00	62.50 500.00	62.50 500.00	62.50 500.00
	242 UK	**148.28 1,186.27**	148.28 1,186.27	**148.28 1,186.27**	148.28 1,186.27	148.28 1,186.27	**148.28 1,186.27**	148.28 1,186.27	148.28 1,186.27
	484 UK	-	**296.57 2,372.55**	-	296.57 2,372.55	296.57 2,372.55	-	296.57 2,372.55	296.57 2,372.55
	980 UK	-	-	-	**600.49 4,803.92**	600.49 4,803.92	-	**600.49 4,803.92**	600.49 4,803.92
	1960 UK	-	-	-	-	**1,200.98 9,607.84**	-	-	**1,200.98 9,607.84**
Maximum outdoor connections with 26RU		27	18	153	148	74	369	370	370
Max. speed (8SS)		1.18 Gpbs	2.37 Gbps	1.18 Gbps	4.8 Gbps	9.6 Gbps	1.18 Gbps	4.8 Gbps	9.6 Gbps
Implemented technologies		OFDMA lower latency and higher number of users; WPA 3 (security), Color BSS (interference), Target Wake Time (For IoT application needed for battery saving).							
Simultaneous connection		8-9 users / connections							

Analysis and calculations: Telecom Advisory Services

Based on the data of the table above, it infers that **WiFi 6 technology possesses** at least **two advantages** that promote performance improvement:

- The creation of Resource Units (RU) that represent the subdivision of the original channel to transport information from several users at the same time **using OFDMA technology**. In other words, a 20MHz channel can have up to 9 subdivisions of 26 RU dimension in 2MHz of bandwidth. In turn, the same channel can also have 52 RU in

4MHz subdivisions; while, in 8MHz subdivisions reach up to 102 RU; and finally, in the entire channel, up to 242 RU can be achieved. With this, it is possible to transmit information for up to 9 users in a 20MHz channel, 18 in a 40MHz channel, 37 in an 80MHz channel and 74 users in a 160MHz channel.
- The **maximum modulation** type **supported is 1024-QAM**, which allows transmitting up to 10 bits per symbol in a period of 13.6μs. This means that maximum speeds of 9.6 Gbps can be achieved with the occupation of a full 160MHz channel with 8 unique transmission data sources or *spatial streams* (8SS).

With this information, it is important to note that, for example, in a 20 MHz channel, the maximum speed can be close to 1.18 Gbps (8SS), for 9 connections that can be accommodated (see Table 2). It is also important to note that the implementation of the standard for outdoor equipment could occupy a maximum of 60 MHz in the 2.4 GHz band, 340 MHz in the 5 GHz band, and 850 MHz in the 6 GHz band.

For the set of bands, calculations show that WiFi 6 could operate in 2.4 GHz with 20 MHz and 40 MHz configurations, hosting up to 27 connections with 26 RU[58] . Meanwhile, with channel aggregation, with the 5 GHz and 6 GHz bands, in 20 MHz, 40 MHz, 80 MHz or 160 MHz configurations, for example, with 102 RU, it could host up to 118 connections[59] with speeds of 500 Mbps. However, it must be taken into account that these configurations are the theoretical ones established by the standard; and, therefore, practical configurations could cover a larger number of connections through channel sharing mechanisms (1:n), but certainly with lower capacity.

Next, considering that one of the possibilities for discussing the use of WiFi 6 in Brazil is only the low band access for outdoors, the previous information will serve to analyze scenarios that could restrict expansion and, therefore, affect the economic impact of WiFi 6.

b) Increasing broadband coverage and improving affordability

Considering the position of restricting the upper part of the 6 GHz band for outdoor use of WiFi 6 technology, it must be taken into account that radio equipment for point-to-point or point-to-multipoint links that could or do operate in this band; and, that have been developed for fixed wireless networks (typically WISPs) would have to partially migrate or avoid deployment in this area of the band. Therefore, there would not only be a reduction in the economic value that the technology can generate, but also the costs of user migration and the reduction in capacity that the 2.4 GHz, 5 GHz and lower 6 GHz bands could provide.

From a technical point of view, the 6 GHz band for WiFi 6 outdoor use is defined through the power characteristic of the equipment (*standard power*); that is, it occupies the UNII5 (5925-6425: 500MHz) and UNII7 (6525-6875: 350MHz) band classification; while, for indoor use of the technology, it is defined by the *low power indoor* (LPI) characteristic that could occupy

[58] 9 connections per channel supported on 3 channels of 20 MHz in the 2.4 GHz band each for a total of 27 total connections.
[59] 2 connections over 3 20MHz channels in the 2.4GHz band, plus 8 connections over 4 80 MHz channels in the 5 GHz band, plus 8 connections over 10 channels in the 6 GHz band for a total of 118 total connections.

the entire 1,200MHz space. In practical terms, for the installation of this type of networks, this band could support the deployment in rural areas, through the so-called WISPs.

In the case of restricting access to the upper part of the 6 GHz band, the first limiting aspect is the ability to accommodate more users in the 350MHz (UNII-7) that can be allowed in possible outdoor operations for WiFi 6. The 4 GHz and 5 GHz bands accommodate a maximum number of connections between 40 and 50; whereas, with the specification of the 802.11ax standard with the entire 6 GHz band, the between 110 and 120 connections could be established; that is, between 2.4 and 2.75 times more.

Thus, if we take as an average scenario of WiFi 6 deployment in a 102 RU configuration, for channel aggregation with the 2.4GHz, 5 GHz and 6 GHz bands, the restriction of the latter band (Δ *Cap*), would represent a 27.12% lower deployment capacity of users that would have to be hosted in the lower bands (see Table 3 and Eq. 3).

Table 2. Analysis of allowed connections in WiFi 6

Features	2.4 GHz (20MHz)	5 GHz (80MHz)	6 GHz (80MHz)	
			UNII-5	UNII-7
Number of outdoor channels	3	4	6	4
Units 102 RU	2	8	8	8
Maximum Connections	**6**	**32**	**48**	**32**

Analysis and calculations: Telecom Advisory Services

$$(Ec. 3) \quad \Delta Cap = \frac{Cap_{6GHz\ alta}}{Cap_{6GHz\ total}} = \frac{32}{118} = 27.12\%$$

In the originally applied model, the projected values of connections made by WISPs will be impacted by a lower installation rate and even the value of investments to try to maintain current speeds, which will undoubtedly increase the price of wireless solutions for the end customer and impact the affordability of the service.

A.3. Reduction of IoT impact if outdoor use of the 6 GHz band is restricted

a) Accelerated Internet of Things deployment

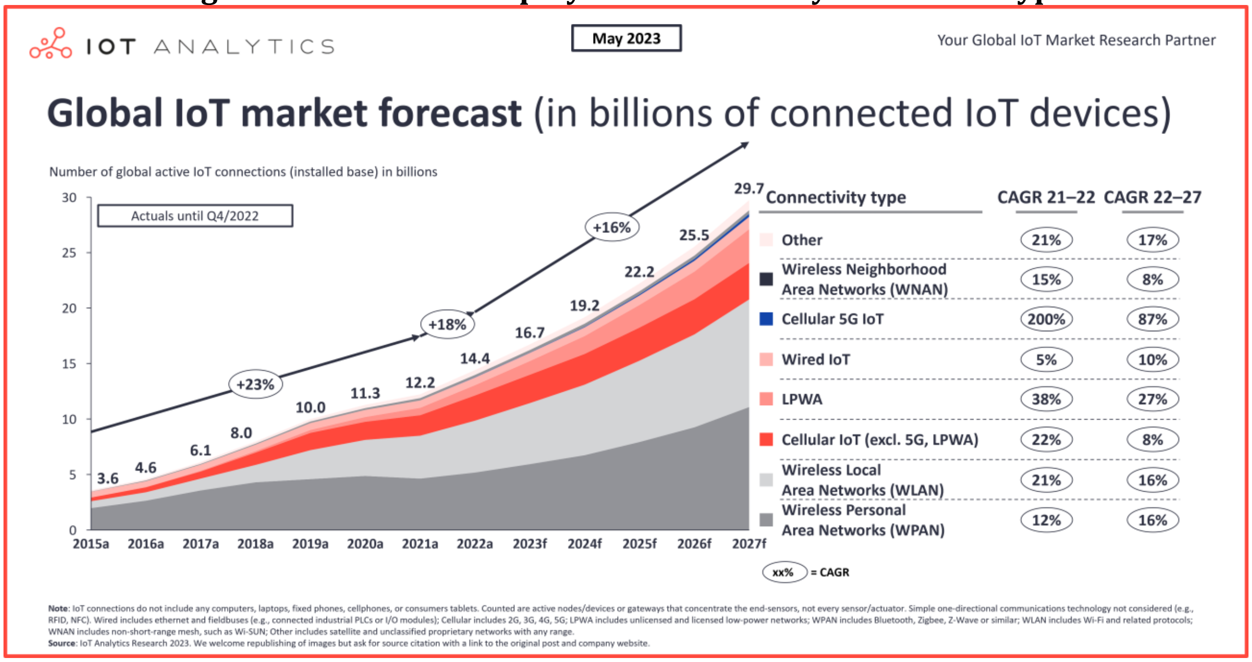
The original model proposed, on the adoption of IoT over WiFi 6, establishes a growing trend of short- and long-range devices. Thus, for example, commercial IoT includes connected devices on large campuses, which are used in corporate[60] and industrial environments[61] . The various types of applications depend on the configuration of the type of network in which IoT devices can be installed. Thus, according to an analysis conducted by IoT

[60] For example, to improve and collect information for marketing and study consumer habits, inventory control, health care, among others.

[61] It covers utility usage and can even help with critical infrastructure management such as traffic management on bridges and railways, as well as energy monitoring at wind farms (https://www.dqecom.com/resources/tech-talk/iot-impact-bandwidth/). (https://www.dqecom.com/resources/tech-talk/iot-impact-bandwidth/)

Analytics[62] , by 2022, there will be 14.4 billion IoT devices connected worldwide, which means 18% compound growth compared to 2021 and a projection of 29.7 billion by 2027 (see Figure 4).

Figure 4. IoT devices deployed worldwide by connection type.



Source: IoT Analytics.

Along the same lines, the research shows graphically that approximately 90% of devices are connected through topologies designed for indoor or mobile technologies (see Table 3).

Table 3. Projection of IoT devices by type of connection

Connection type	Devices to 2022 (billions)	Percentage 2022	CAGR 2022-2027	Projected devices to 2027 (billions)	Percentage 2027
Another	0.4	2.78%	17%	0.88	2.94%
WNAN	0.3	2.08%	8%	0.44	1.48%
5G Cellular	0.01	0.07%	87%	0.23	0.77%
Wired IoT	0.6	4.16%	10%	0.97	3.24%
LPWAN	1	6.94%	27%	3.30	11.09%
Cellular IoT	2.3	15.96%	8%	3.38	11.35%
WLAN	4.6	31.92%	16%	9.66	32.44%
WPAN	5.2	36.09%	16%	10.92	36.68%
TOTAL	**14.41**	**100%**		**29.78**	**100%**

Source: IoT Analytics, Analysis and calculations: Telecom Advisory Services.

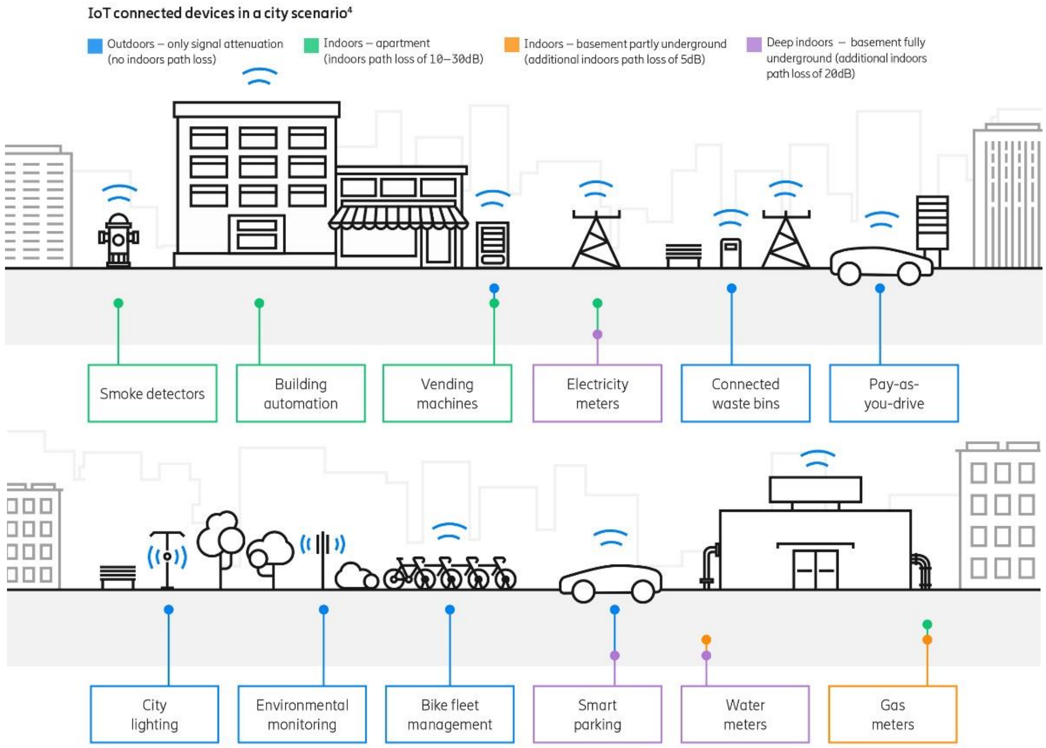
Personal area networks (WPAN), local area networks (WLAN), cellular (2G, 3G, 4G, 5G) and wired (PLC, I/O modules) are connection mechanisms for indoor or outdoor networks through technologies other than WiFi. In other words, of the total projected growth of IoT devices in the world, 9.02% of terminals that could work in conjunction with WiFi 6 technology by 2022, and 12.57% by 2027 (in LPWAN and WNAN topologies) could be

[62] Source: IOT Analytics. (2023). "State of IoT 2023". https://iot-analytics.com/number-connected-iot-devices/

affected in some way by the partial restriction of the 6 GHz band due to possible developments for outdoor data transmission.

In that sense, it is important to add that WiFi 6 presents interesting features (such as TGT, WPA3, OFDMA) for the specific management of IoT over the LPWA network that handles low power communications over long distances and allows transmitting low amounts of data and in multiple scenarios such as industrial corporate networks in large facilities, agriculture, healthcare and smart cities. Similarly, a neighborhood area network (NAN), where a group of devices are connected within a residential or community area, usually relies on wireless technology, such as WiFi, to establish connectivity between devices. Therefore, these networks promote the deployment of IoT *outdoor* technology for solutions aimed at utility providers and home energy management systems, improving, for example, the control, monitoring and management of energy in real time (see Figure 5).

Figure 5. IoT Device Connectivity Scenarios



Source: Ericsson[63] *.*

For Brazil, the Brazilian Association of Internet of Things (ABINC), mentions that the country has undergone significant growth since 2019. In addition, it suggests that the most advanced sector in IoT connections is manufacturing, although an expansion is expected in services, such as health, agribusiness and smart cities[64] is expected. Along these lines, according to *Statista Market Insights*, the revenue market by IoT segment in Brazil, by 2023, is mostly

[63] Source: Ericsson. https://www.ericsson.com/en/reports-and-papers/mobility-report/articles/connecting-things-in-the-city-wef-edition

[64] Source: ABINC. https://abinc.org.br/o-caminho-promissor-da-iot-no-brasil/

represented (65.15%) by indoor deployments; while 34.85% could be considered IoT developments compatible with large areas[65] (see historical series in Table 4). Consequently, if the proportion of spectrum that could be restricted in the high 6 GHz band corresponds to 58.33% of the total[66] **, the percentage value that would directly impact the economic balance** (Δ I) **of the IoT segment** if the use of the high 6 GHz band is restricted outdoors **corresponds** to **38% in 2023** and 45.64% in 2034 (see Table 4 and Eq. 4).

Table 4. Revenues by IoT segment in Brazil (Billion US$)

Segment	2023	2024	2025	2026	2027	2028	% 2023	% 2028
Consumer IoT	2.48	2.61	2.71	2.79	2.89	2.99	25.13%	17.91%
Healthcare IoT	0.96	1.11	1.24	1.37	1.49	1.63	9.73%	9.77%
Industrial IoT	5.21	6.23	7.17	8.07	8.99	9.89	52.79%	59.26%
Smart Cities	1.22	1.44	1.63	1.81	2.00	2.18	12.36%	13.06%
Total	**9.87**	**11.39**	**12.75**	**14.04**	**15.37**	**16.69**	**100.00%**	**100.00%**

Source: Statista. Analysis: Telecom Advisory Services.

$$(Ec. 4) \quad \Delta I_{2023} = \left(\frac{\Delta AB_{6GHz\ alta}}{AB_{6GHz\ Total}}\right)\left(\frac{Industrial_{IoT} + Smart\ Cities}{Total}\right) = \frac{700}{1200} . \frac{(5.21 + 1.22)}{9.87} = 38\%$$

A.4. AR/VR impact curtailment if outdoor use of the 6 GHz band is restricted

In the model proposed, the economic impact of the adoption of 802.11ax in the 6 GHz band, based on the development of virtual reality and augmented reality, is focused on the design of hardware and software in various personal and industrial environments.

Several of the virtual reality and augmented reality applications are integrated for personal area network (WPAN) devices such as mobiles or glasses that present additional information to that of physical reality. In addition, they are being implemented in ecosystems such as manufacturing, such as assisted picking for logistics or remote assistance for healthcare. In these cases, it is important to highlight the operation of these devices in a network environment such as LPWA or WNAN.

In this sense, the fundamental point is to determine the market share of AR/VR equipment in applications and use cases in sectors such as agriculture, manufacturing, logistics or healthin order to estimate the level of impact that this segment could suffer due to the restriction of the 6 GHz band for WiFi 6 outdoors. In this context, Verizon[67] indicates the need to understand that the convergence of these technologies is revolutionizing sectors such as remote work, data visualization, and interpretation of complex information sets, as well as the development of robust management and monitoring systems. In other words, a possible impact of IoT devices working in extended network environments could also

[65] Industrial IoT and Smart Cities
[66] Of the 1200 MHz available for outdoor applications in the 6 GHz band, the 700 MHz corresponding to the high band represents 58.33%.
[67] Source: Verizon. "How AR and VR technology can enhance IoT applications" https://www.verizon.com/about/blog/vr-and-iot

determine a reduction in the impact that AR/VR would have with a restriction in the use of the 6 GHz band.

According to *ABI Research* the market for active users of Augmented Reality in Latin America by 2030 is segmented between indoor (47%), and outdoor uses (53%) in different industries, according with cases uses of AR/VR in these environments.

That is, in Brazil would be represented by a proportion of devices that would have to avoid operating in the upper 6 GHz band; and, that would correspond to 31.34%, by 2023, and 30.92% by 2034, of reduction, both in device generation and software development in open environments (see Eq. 5).

$$(Eq. 5)\quad \Delta D_{2023} = \left(\frac{\Delta AB_{6GHz\,alta}}{AB_{6GHz\,Total}}\right)(Outdoor\ share\ restricted) = \frac{700}{1200}.53.72\% = 31.34\%$$

A.5. Reduction of impact on Municipal Wi-Fi if outdoor use of the 6 GHz band is restricted

The model initially proposed, with the use of the entire 6 GHz band for the WiFi 6 and 6E standard, establishes at least two important points for the development of municipal Wi-Fi points in the different localities of Brazil: (i) the increase in the use of traffic in the 6 GHz band, and (i) the number of people, belonging to households, who will benefit from Internet access through these infrastructures. In this regard, it should be considered that the design of Municipal Wi-Fi networks requires establishing, among others, the user's traffic demand profile (CM) and its usage factor (FU), the number of total (US) and simultaneous users in the busiest hour (FS), and the available bandwidth (AB) (see Eq. 6).

$$(Ec. 6)\qquad AB_T = US.FS.\sum_{i=1}^{n} CM_i.FU_i$$

That is, the demand profile and its usage factor represent the maximum download capacity for the different requirements (web pages, e-mail, social networks, calls, video, etc.) and their percentage of use, respectively.

If we take an example for an average user in Brazil, with four (4) major consumer services (videoconferencing, calls, general browsing and music or video streaming), the traffic demand for each service is given by the download capacity. Thus, for web browsing, a user accesses every 20 seconds to pages whose size is around 2.17 MB (2,225.65 KB) while, for other applications such as video streaming or videoconferencing, the average is around 3.9 MB (see table 6).

Table 6. Size and capacity of most visited pages and applications in Brazil

Type	Most visited pages Brazil	Size (T) KB	Capacity (CM) Kbps
Navigation	Google	606.80	$CM = \frac{\bar{T}}{t} \cdot \frac{8\ bits}{1\ byte}$ $= \frac{2{,}225.65KB}{20s} \cdot \frac{8\ bits}{1\ byte} = 890.26\ Kbps$
	YouTube	3,276.80	
	Balloon	6,041.60	
	Instagram	2,662.40	
	UOL	3,686.40	
	Facebook	337.20	
	Twitter	1,740.80	
	CAIXA	0.90	
	Free Market	114.80	
	Amazon	3,788.80	
Videoconferencing (e.g. Skype)			3,000
Video streaming (e.g. YouTube)			4,800
Calls / Social Networks (e.g. WhatsApp)			12.33

Source: Most visited pages Brazil: SEMRUSH[68] , Capacity Analysis: PINGDOM[69] . Calculations: TELEADVS

On the other hand, the usage factor would be given by the daily time spent by an average user, which, for the most part, is linked to Internet browsing (9h 32m - 35.2% see table 7). According to the report Statistics of the digital situation in Brazil in 2023 published by *We Are Social*[70] , users spend 70.4% of their time on the proposed services.

Table 7. Common time of use of applications over the Internet in Brazil

Internet usage time	Hours	Minutes	Total (h)	% Usage
Surfing the Internet	9	32	9.53	35.2%
Broadcast and Streaming (Video)	4	29	4.48	16.6%
Social Networks (Call)	3	46	3.77	13.9%
Podcast (Videoconference)	1	17	1.28	4.7%
Others	7	61	8.02	29.6%

Source: We Are Social, Analysis: Telecom Advisory Services

Therefore, if we assume that capacity is reduced by half due to simultaneous users, this factor is assumed to be 0.5. In this sense, considering that Table 8 contains the usage and capacity information of the different services, Equation 7 establishes that the **reduction of users in Municipal Wi-Fi would be 24.82% in** case of restricting the upper part of the bandwidth of the 6 GHz frequency.

Table 8. Capacity and percentage of use of applications in Brazil

Services	Capacity (Kbps)	% Usage
Navigation	890.26	35.2
Video	4,800	16.6
Calls / Social networks	12.33	13.9
Videoconference	3,000	4.7

Source Analysis: Telecom Advisory Services

68 Source: https://www.semrush.com/trending-websites/br/all
69 Source: https://tools.pingdom.com
70 Source: We Are Social, "Statistics of Brazil's Digital Situation in 2023" https://datareportal.com/reports/digital-2023-brazil

$$(Ec.7) \quad AB = US.(0.5)\{(890.26 * 35.2\%) + (4800 * 16.6\%) + (12.33 * 13.9\%) + (3000 * 4.7\%)\}$$

For 850 MHz Bandwidth (total outdoor bandwidth at 6 GHz), the number of users that a WiFi hotspot could reach is US_1 =2,213; while, for 500 MHz Bandwidth (lower part of the 6 GHz band) the maximum number of users is US_2 =1,663. Therefore, the **percentage variation of users that a Municipal Wi-Fi site could host due to the decrease in bandwidth corresponds to 24.82%**.

A.6. Reduction of impact on Free Hotspots if outdoor use of the 6 GHz band is restricted

The economic impact of restricting the high end of the 6 GHz band for free use in *Free Hostspots* is similar to that made for municipal WiFi networks due to their open nature for Internet access by users. In other words, **the possible limitation of the use of the 6 GHz band at the high end**, by WiFi 6 and 6E technology, outdoors, **could define the number of possible users at 24.82% less.**

A.7. Spectrum designation alignment impact reduction if outdoor use of the 6 GHz band is restricted

The original model defines the main inputs for the alignment of spectrum designation with advanced economies as the amount of hardware, software, services and prices that could be commercialized as a result of the use of the 6 GHz band. In this sense, if a possible restriction of the upper part of the 802.11ax band for outdoor use is generated; and, considering that the use of IoT and AR/VR devices outdoors (Smart Cities and Industrial) are linked. **The reduction percentage that would apply in this section would correspond to a joint value that comes from the decrease of 38% in IoT and 31.34% in AR/VR for the year 2023.**

Furthermore, a potential restriction on the use of the high end of the 6 GHz band for outdoor IoT and AR/VR device access could increase the price of equipment related to leveraging economies of scale in those sectors.

A.8. Reduced impact of increased routing capacity if outdoor use of the 6 GHz band is restricted

In the original model proposed in this section, the variables of interest, which may be impacted in the event of a possible restriction of the upper part of the 6 GHz band, are linked to the percentage of savings in investment in mobile network traffic overflow infrastructure over the suburban and rural population. According to the assumed data, 15% and 5% savings are realized, in each zone, respectively.

These constants could be directly affected by the **24.82% reduction in WiFi accesses that would be available for traffic overflow on mobile networks.** In other words, the impact in suburban areas would be reduced to 11.27% and in rural areas by 3.76%.

A.9. Speed impact decrease if outdoor use of the 6 GHz band is restricted

In the model originally proposed, the relevant variables that determine an impact due to the restriction of the high part of the 6 GHz band for outdoor environments are: (i) the saturation speed of access to an indoor user; and, (ii) the number of households accessing a plan below that speed. In this case, without access to the high part of the 6 GHz band in outdoor environments, **the original values do not change because access to the high band in indoor environments is not restricted.**

A.10. Consumer surplus reduction if outdoor use of the 6 GHz band is restricted

In this regard, it is important to note that there are two important variables that drive the impact of WiFi 6 adoption: (i) the number of fixed connections; and, (ii) the average speed variation for connections occupying the 6 GHz band; that is, there is a relationship between speed increase and consumer benefit.

In this case, in the event of a possible restriction of the high part of the 6 GHz band outdoors, the economic impact **will not be affected** because the high part is not restricted in indoor areas.

A.11. Business internet traffic decrease if outdoor use of the 6 GHz band is restricted

In the original model proposed, the variables that could influence a change in the economic impact due to the restriction of the upper part of the 6 GHz band are linked to the projection of business traffic and the relationship between traffic resolved by wired and wireless means.

In this sense, the traffic or information flow is directly related to the maximum speed that can be achieved with the channeling scheme and bandwidth allowed; however, it must also be considered that the potential impact would have to be distributed exclusively for the indoor environment.

In other words, a potential limitation on the upper part of the 6 GHz band outdoors could affect the projection of enterprise traffic at the same rate as the average speed of home internet connections is reduced.

A.12. Reduction in consumer and producer surplus impact from Wi-Fi equipment, if outdoor use of the 6 GHz band is restricted

For this case, it is fundamental to understand that the possible economic impact of the restriction of the 6 GHz band for the 802.11ax standard would come from the development and sale of equipment for external wireless use that is exported or imported to Brazil. Devices such as wireless speakers, security systems, access points, external adapters, routers, gateways, are the most common items that could be built; however, the potential restriction of the upper part of the 6 GHz band would come from the relationship between the total manufacturing of equipment with wireless technology and the sales of items operating in the 6 GHz band to deploy the 802.11ax standard.

According to the report "*Unlicensed Spectrum and the U.S. Economy*" (Consumer Technology Association, 2022), the incremental value of sales related to outdoor equipment occupying unlicensed spectrum in the United States is 6.72% (see Table 9), a value that will apply directly to the Brazilian case.

Table 9. Sales of unlicensed spectrum equipment for outdoor use

Wireless products for outdoor use	Incremental Sales Value ($ Million)	Percentage
Drones and Radio-Controlled Hobby Craft	$ 2,700.00	3.39%
Point-to-Point and Point-to-Multi-Point	$ 1,320.00	1.66%
Mesh Wi-Fi Systems	$ 1,089.00	1.37%
Smart Meters and Mobile Meter Readers	$ 155.00	0.19%
Portable Navigation Devices That Are Connected	$ 42.00	0.05%
Automatic Vehicle Identification Systems (AVIS)	$ 40.00	0.05%
Walkie-Talkies (Family Radio Service)	$ 10.00	0.01%
Intelligent Transportation Systems	$ -	0.00%
Total sales	$ 79,758.00	**6.72%**

Source: CTA, Analysis: Telecom Advisory Services

Additionally, the total value that would be affected is related to the restriction to the high bandwidth part of these equipment that are linked to the operation in outdoor environments. That is, 41.18% of restricted bandwidth is applied to the value of sales of outdoor equipment; thus, **the percentage that affects the consumer's and producer's profit from the manufacture of outdoor WiFi equipment corresponds to 2.77%.**