Sensitivity Options of 5G Non-Standalone Deployment Strategies: A Simulation Model for Emerging Countries

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Abstract **– Deploying cutting-edge 5G technology is a major challenge for mobile operators in emerging countries, facing hurdles on both the technical and economic fronts. This study provides specific ways in which mobile companies in developing countries can use 5G technology to benefit economically. This study utilizes a sensitivity option with a techno-economic analysis (TEA) simulation model to evaluate business options influencing successful 5G non-standalone (NSA) deployment in these markets, using Indonesia's Bandung City as a case study. The analysis finds that Bandung requires 172 5G gNodeBs to meet traffic demand. Further, the 5G NSA deployment delivers strong key performance indicators (KPIs), with good signal synchronization received power (SS-RSRP) and signal-to-interference noise ratio (SS-SINR). Sensitivity analysis identifies the gNodeB amount as the most critical parameter impacting overall 5G NSA deployment feasibility. Overall, the analysis indicates mobile operators can recover investments after 3 years and 10 months, providing evidence for the viability of 5G NSA deployment in Bandung's urban area.**

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1. Introduction

The fifth-generation network, IMT-2020 or 5G, is designed to quickly transmit large amounts of data and increase the amount of mobile traffic data that can be shared among multiple devices. As a result, the volume of data transferred through mobile devices is expected to increase significantly. By 2020, global mobile traffic is projected to increase by 200 times. By 2030, it is forecasted to increase by 20,000 times [1]. In emerging countries, particularly Indonesia, traffic congestion on the network has been reported in major cities such as Jakarta, Bandung, Medan, Bogor, Depok, Tangerang, Bekasi, Yogyakarta, Semarang, Surabaya, Pontianak, Denpasar, and Makassar. Bandung City was selected as one of the testbeds for the 5G non-standalone (NSA) model because it is the capital city of West Java, Indonesia. In addition, it has a large consumer base and a robust 4G network infrastructure to support it.

Previous research indicated that there is a pressing need for large amounts of traffic data in Indonesia, and three cities were chosen, namely, Jakarta, Surabaya, and Medan, as design models because they all have a high demand for traffic data [2]. Additionally, another research found that implementing a 5G network is feasible in a dense urban area of Jakarta City [3]. However, a business sensitivity options study has yet to be done to explore the technology and economic factors that may affect the rollout of a 5G network in an urban area of Indonesia, particularly under the NSA implementation model.

Therefore, this study aims to examine, from a technology and economic perspective, whether it is possible to deploy a 5G cellular network in an urban area of Bandung City using the mid-band 3.5 GHz frequency, which has a good balance of capacity and coverage for 5G. In order to implement 5G NSA in Bandung City, a technical analysis of capacity and coverage planning will be conducted, which includes determining the expected subscribers over the next six years, the traffic demand, and the required amount of gNodeB. In addition, the feasibility and its business sensitivity options are required to be investigated to determine whether the deployment of 5G NSA is feasible and profitable for cellular operators, as well as assess the sensitivity parameters of the techno-economic factors that significantly affect the deployment.

This study is organized into five sections. The first section is the introduction. The second section elaborates on the underlying theories of 5G, including its deployment model types and the techno-economic approach. The third section discusses the methodology used to gather the required data on the technical and economic aspects of 5G NSA deployment in an urban area of Bandung City. Then, the study's results and analyses are presented in the fourth section. Finally, the conclusion of this study is presented in the fifth section.

2. Underlying Theories

This section provides an overview of the underlying technical and economic theories of 5G network deployment strategies. First, the 5G technology itself will be introduced, including key usage scenarios, frequency ranges, and architecture options. Then, the technical planning considerations of capacity, coverage, and antenna selection will be discussed. Finally, the economic feasibility analysis encompassing cost structure, financial viability parameters, and sensitivity analysis will be outlined.

2.1. 5G Technology

In cellular telecommunications technology, 5G technology became the first radio system to support a radio system with a high-frequency spectrum and is predicted to use frequencies of 1–100 GHz [4]. A high spectrum range can provide a good combination of high capacity, high data rates, and ultra-reliability. Future 5G mobile applications are divided into three major scenarios [5]:

- Access to multimedia, human-centric services, and data content is a fundamental requirement for mobile communications, and the first scenario, eMBB, can boost the mobile broadband capacity to provide such access.
- Vertical industries and IoT devices rely on mMTC scenario for communication since it enables large capacity of connected devices.
- Automated cars, remote medicine, and other industries that require minimal latency can utilize uRLLC scenario.

All 5G scenario capabilities require diverse frequency spectrums and different characteristics. For example, Table 1 shows that all three 5G scenarios can be distinguished based on usage scenarios, frequency categories, characteristics, frequency range, and bandwidth [6].

Table 1. 5G usage, frequency, characteristics, and range

Usage scenarios	**Frequency categories**	**Characteristics**	**Range frequency and bandwidth**
eMBB	Mid and high band	Coverage, capacity, and super data layer	2-6 GHz and > 6 GHz
mMTC	Low and mid band	Coverage and capacity layer	< 2 GHz and 2-6 GHz
uRLLC	High band	Super data layer	> 6 GHz

2.2. 5G Deployment Standards

Standards for the deployment of 5G networks are being developed by the 3rd Generation Partnership Project (3GPP). Both non-standalone (NSA) and standalone (SA) architectures are viable solutions for establishing 5G networks. Cellular operators can select one of the two architectures for 5G deployment depending on cost, spectrum, and infrastructure availability. Table 2 compares 5G SA and NSA designs from three perspective points [7].

Table 2. Comparison of 5G SA and 5G NSA architecture

Perspectives		**5G SA**	**5G NSA**
Investments required based on the time frame	Short term	Big	Small and medium
	Long term	Unknown	Big
Availability of spectrum frequency	Sub 6 GHz	Good coverage	Relying on an LTE network for good coverage
	mmWave	Hotspot-based	Hotspot-based
Services offered	eMBB, mMTC, and uRLLC	eMBB, mMTC, and uRLLC	eMBB only

2.3. Technical Planning Aspect

The 5G NSA deployment's technical planning aspect is divided into capacity and coverage. The term 'capacity planning' refers to the process of evaluating the quality of a network and its capacity to determine the required resources to accommodate the expected mobile traffic with sufficient throughput, spectrum range, and mobile network requirements. The subscriber numbers, the volume of traffic on demand, the available throughput, and the capabilities of the individual devices are all variables that might impact the network's configuration [8]. On the other hand, this research's coverage planning considers three crucial parameters: link budget, model of propagation, and coverage antennas. Furthermore, a tri-sectoral antenna was applied since it can vastly enhance the performance of 5G networks in terms of range and quality. Afterward, a simulation using the Forsk Atoll network simulator will be conducted.

2.4. Economic Planning Aspect

The economic aspect determines whether a business is worthy of running, and decisions are taken based on a process of technical and economic calculations. The economic aspect is carried out in several stages: cost structure, feasibility, and sensitivity calculations so that businesses can estimate and avoid losses [9]. First, the cost structure is divided into CAPEX and OPEX. Then followed by calculating four crucial feasibility parameters: (i) NPV; (ii) IRR; (iii) PBP; and (iv) PI. Finally, a sensitivity analysis is done based on five parameters: the CAPEX, the number of subscribers, the amount of gNodeB, the cost for operation and maintenance, and the marketing cost.

3. Methodology

Two of the most critical aspects of this techno-economics research are process design and data collection. The input data, process design, and planning were gathered from various sources, including cellular technology experts from leading companies, databases, and reports from cellular providers. Figure 1 depicts the research's techno-economic model framework.

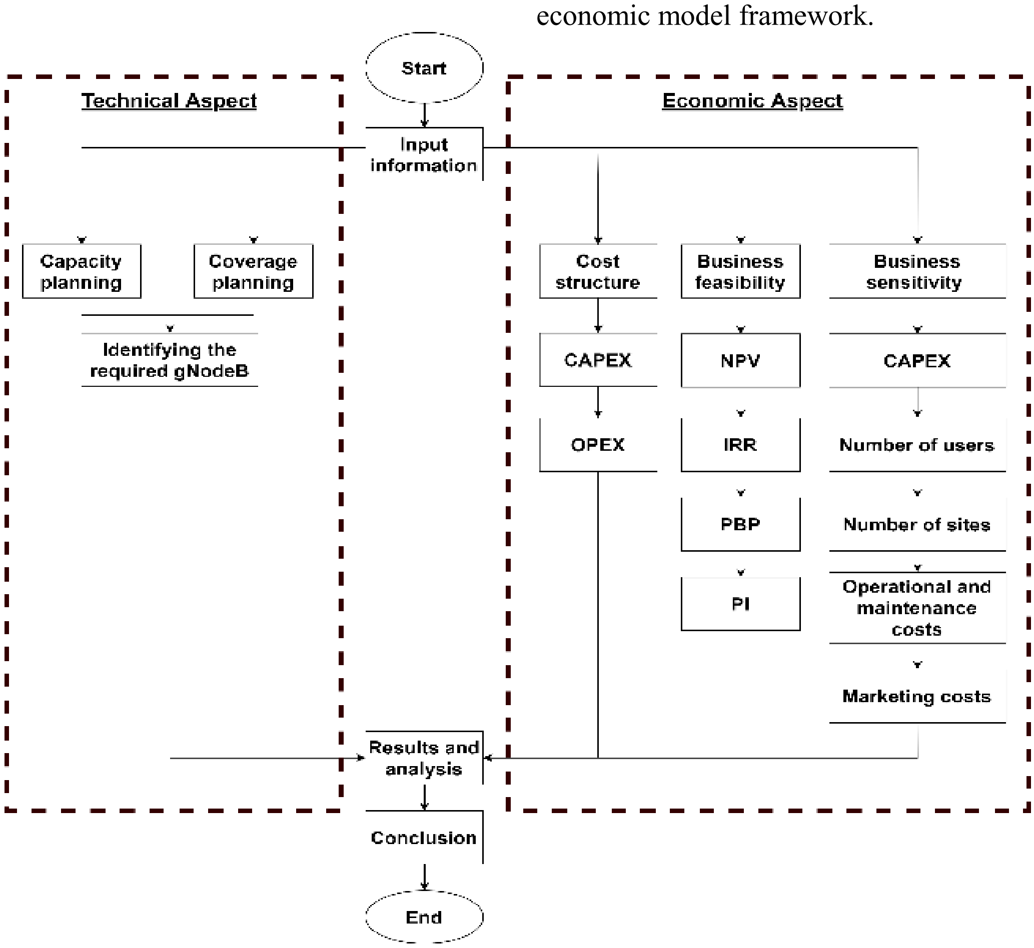

Figure 1. Techno-economic model framework

3.1. Input Information

This research collected data on deploying 5G networks in Bandung City (167.31 km^2), with a 2020 population of 2,503,780 [10]. Bandung attracts migrants due to its tourism and universities. The data will enable the analysis of technical and economic aspects. Figure 2 maps Bandung City.

Figure 2. Map of the urban area, Bandung City

3.2. Capacity Planning Technical Aspect

This study's technical analysis involves capacity and coverage planning. Factors like 5G subscribers, data rate, system capacity, and traffic demand must be considered when deploying 5G NSA in Bandung City to acquire sufficient gNodeB.

3.2.1. 5G User Projection

The 5G subscribers' projection is influenced by the initial market capacity that can project the market going forward. The initial market capacity is obtained by considering the annual entrants in an area to be designed. Therefore, the number of 5G subscribers' projection can be calculated using Equation (1).

$$N(t) = M\left[\frac{1-e^{-(p+q)}}{1+\frac{p}{q}e^{-(p+q)}}\right] \quad (1)$$

where $N\ (t)$ is the subscribers' number, M is the urban market capacity, p is the innovation coefficient where it must be greater than 0, and q is the imitation coefficient where it must be 0 or above.

3.2.2. Traffic Demand Projection

The projected traffic demand in capacity is the main consideration in estimating the amount of required gNodeB. The region's population density affects the traffic demand projections. In order to calculate it for the 5G NSA implementation, the following Equation (2) is utilized.

$$\rho = \frac{P \cdot T \cdot M_S}{A} \quad (2)$$

where ρ is the number of populations, T is the smartphone penetration, Ms is the market share of a cellular operator, and A is the surface area of Bandung City. Table 3 shows the results of processing data on the population density of Bandung City.

Table 3. The projected population density in 2026

Population density	Number of populations	Smartphone penetration	Market share	Surface area
2,652 users/km^2	3,522,747	0.28	0.45	167.31 km^2

3.2.3.System Capacity Calculation

The number of subscribers is considered at the planning stage of capacity in design. This method seeks to identify the required amount of gNodeB in a given region based on their calculated capacity. Next, the needed capacity is calculated by utilizing the traffic demand and spectral efficiency factors. Equation (3) is utilized to calculate the system's capacity.

$$Capacity = B_w \cdot N_{site} \cdot N_{cell} \cdot Spectrum_{eff} \quad (3)$$

where B_w is the bandwidth used in this research, N_{site} is the amount of gNodeB, N_{cell} is the number of cells, and $Spectrum_{eff}$ is the spectrum efficiency factor.

3.3. Coverage Planning Technical Aspect

Several parameters that have a significant role in coverage planning are taken into account, such as, the receiver sensitivity and the antenna gain. Moreover, the MAPL is also crucial for coverage planning. Therefore, when calculating MAPL values, propagation models employed in the frequency spectrum are considered. In addition, MAPL computations vary by area type, including dense urban, urban, suburban, and rural. Hence, proper cell radius can be defined depending on the scenario.

3.3.1. Link Budget Calculation

In 5G, there are body blocks, losses, foliage loss, and rain/snow attenuation. The link budget calculation will get the MAPL value, or the maximum weakening of the signal received between the mobile antenna and the mobile station antenna on the uplink and downlink. Therefore, Equation (4) is used to decide the link budget of this research [12].

$$Link\ Budget = Transmitter\ Power_{TX} + Antenna\ Gain_{TX} - Cable\ Loss_{TX} + Antenna\ Gain_{RX} - Cable\ Loss_{RX} - Path\ Loss_{Propagation\ model} - Penetration\ Loss_{dB} - Foliage\ Loss_{dB} - Body\ Loss_{dB} - Interference\ Margin_{dB} - Rain|Ice\ \ Margin_{dB} - Slow\ Fading\ Margin_{dB} - Penetration\ Loss - Attenuation \quad (4)$$

The 5G NSA path loss model utilizes the 3GPP standardization based on technical specification version 38.901. In this research, the path loss propagation model is assumed to be a Line of Sight (LOS), meaning there are no obstacles between the transmitter and the receiver. Therefore, it can be calculated using Equation (5).

$$Path\ Loss = 28.0 + 40\ log_{10}(d_{3D}) + 20\ log_{\ 10}(f_c) - 9log_{10}[(d'_{BP})^2 + (h_{BS} - h_{UT})^2] \quad (5)$$

where d_{3D} is the resultant distance between h_{BS} and h_{UT}, f_c is the frequency carrier, d'_{BP} is the breakpoint distance, h_{BS} is the height of the base station, and h_{UT} is the height of the user terminal.

3.3.2.Coverage Area Calculation

The coverage calculation uses link budget analysis to determine the gNodeB quantity based on each gNodeB's coverage distance. Knowing the total area and a gNodeB's coverage area helps to determine the required gNodeB amount [13]. 5G employs three-sector antennas per cell for increased capacity and range, as in Figure 3. Equation (6) calculates the coverage area.

$$Coverage\ Area = 1.94\ \cdot (Cell\ Radius)^2 \quad (6)$$

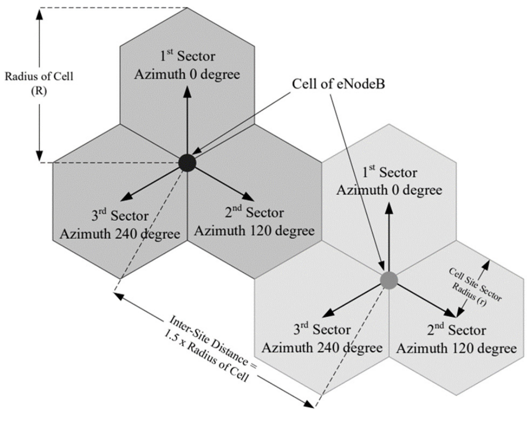

Figure 3. Tri-sectoral antenna for coverage calculation

3.4. Final Required Amount of gNodeB

Capacity and coverage planning approaches are employed to calculate an approximate amount of required gNodeB.

Once the amount of gNodeB for each planning approach is obtained, the acquired data will be compared using Equation (7) to select the final amount of gNodeB.

$$Number\ of\ final\ required\ sites = Maximum\ (coverage, capacity) \quad (7)$$

3.5. Network Simulation

To deliver quality, affordable 5G services, operators must optimize network design tradeoffs. This study uses Forsk Atoll to simulate a 5G NSA implementation in Bandung City. The simulation maps the needed gNodeB quantity to achieve acceptable SS-RSRP (signal strength) and SS-SINR (signal quality) for users. Higher values of these parameters indicate better signal and less interference.

3.6. Economic Aspect

The economic aspect determines if a business is viable through economic calculations. Cost estimates, feasibility, and sensitivity parameters anticipate losses. CAPEX is the initial capital investment for assets or infrastructure. OPEX is the daily operating expenses such as maintenance. Economic evaluations use CAPEX and OPEX to decide if a new or growing business is financially feasible.

3.7. Feasibility Study

In the economic feasibility calculation, several parameters are required to be determined, as follows:

3.7.1. Net Present Value (NPV)

NPV is the difference between cash inflows' present value and cash outflows' present value over a period. The interest rate value strongly influences NPV calculation results. If the NPV exceeds 0, the project is feasible for implementation. If NPV equals 0, the project neither gains value nor loses. If the NPV is less than 0, the project cannot generate profit to cover the cost and is rejected. The NPV can be calculated by using Equation (8).

$$NPV = \sum_{time\ =\ 0}^{number\ of\ periods} \frac{Net\ cash\ flow\ of\ a\ period}{(1+discount\ rate)^{time}} \quad (8)$$

3.7.2. Internal Rate of Return (IRR)

IRR is an interest rate value used to measure investment levels. The investment is worth it if the IRR exceeds the applicable interest rate.

On the contrary, the proposed investment does not represent a financially prudent course of action if its estimated internal rate of return fails to surpass the prevailing market interest rate. The IRR value can be obtained by using Equation (9).

$$IRR = low\ interest + \frac{NPV_{low\ interest}}{NPV_{low\ interest} - NPV_{high\ interest}} \cdot (high\ interest - low\ interest) \quad (9)$$

3.7.3. Payback Period (PBP)

PBP states a time period that indicates how long capital is invested until the Break-Even Point (BEP) is reached [14]. If the PBP is larger than the specified PBP investment, then the investment project is not feasible. However, the investment project is still feasible if the PBP equals the specified PBP. On the other hand, if the PBP is less than the specified, the investment project is feasible and can be continued. The PBP can be calculated by using Equation (10).

$$PBP = \frac{initial\ investment}{cash\ in\ flow} \quad (10)$$

3.7.4. Profitability Index (PI)

PI states the comparison of the present value of cash inflow to cash outflow [5]. If the PI is more significant than 1, the project generates value, and the company should continue the project. If PI equals 0, the project generates an uncertain value, and the company may continue or not continue the project. If PI is less than 0, the project cannot generate cost value, and the company should not proceed with the project. The value of the PI can be calculated using Equation (11).

$$PI = \frac{NPV}{initial\ investment} \quad (11)$$

3.8. Sensitivity Study

Sensitivity analysis evaluates uncertainty's influence on business estimates using graphs, math, and statistics. It identifies parameters significantly impacting the economic feasibility over time [15], [18]. This study simulated three scenarios: baseline, optimistic (increased parameters), and pessimistic (decreased parameters). This tested sensitivity under different conditions.

4. Results and Analysis

This section summarizes the key technical and economic insights from the 5G NSA deployment simulation model. The technical analysis examines projected subscriber numbers, traffic demand, propagation modeling, and base station requirements to determine network capacity and coverage needs.

The economic analysis evaluates cost structure, feasibility, and sensitivity metrics to assess business viability. The sensitivity analysis identifies the most impactful factors for successful 5G implementation.

4.1. Technical Planning Aspect Analysis

The technical planning aspect analysis of the 5G NSA network is separated into capacity and coverage planning. Technical analysis will begin by providing a proposed frequency plan for the mid-band frequency spectrum, which is expected to have the potential for good technical aspects to be used as a 5G operating frequency spectrum in Indonesia.

4.1.1. Capacity Analysis of 5G Market User Projection

The 5G NSA subscribers' projection begins with knowing the primary value of the projected future market. It is estimated that 57,000 migrants entered the Bandung City area. This study utilizes six years period for subscribers modeling from 2021 to 2026. Table 4 shows the data on the 5G subscribers from 2021 until 2026.

Table 4. Projected 5G subscribers in 2026

Year	Market capacity	Total of users
N (0) – 2020	-	2,582,148
N (1) – 2021	80, 469	2,662,617
N (2) – 2022	187,668	2,850,285
N (3) – 2023	326,520	3,176,805
N (4) – 2024	499,972	3,676,777
N (5) – 2025	707,098	4,383,875
N (6) – 2026	941,523	5,325,398

4.1.2. Capacity Analysis of Traffic Demand Projection

The market share for 5G, 5G smartphone penetration, population density, and the monthly average demand are all variables that impact the capacity of a telecommunications network [19]. This research uses market share from the largest mobile operator in Indonesia, PT. Telkomsel, with a value approach of 45% and smartphone penetration of 45% [16]. Table 5 shows the results of calculations for the traffic demand projection of Bandung City in 2026.

Table 5. Generated demand traffic projection for 5G NSA

City	Surface area	Monthly demand	Population density	Generated demand traffic
Bandung	167.31 km^2	100 GB	2,652 user/km^2	2.18 Gbps/km^2

4.1.3. Capacity Analysis of Required Amount of gNodeB

In the deployment of a telecommunication network, capacity must be considered.

Other factors affect the system's capacity, such as the selection of frequency and the type of antennas used. The utilized frequency is the mid-band 3.5 GHz with a 100 MHz bandwidth and a 1:2 ratio of time division duplex (TDD) approach [17]. Thus, Table 6 presents the capacity-based amount of gNodeB required for Bandung City.

Table 6. Amount of gNodeB based on capacity approach

Parameters	Uplink	Downlink
Environment	Outdoor	
Sectors	Tri-sectoral (3)	
Bandwidth	100 MHz	
Av. gNodeB capacity	4.22 Gbps	13.15 Gbps
Traffic demand	2.18 Gbps/km^2	
Amount of gNodeB	86	35

4.1.4. Coverage Analysis of Link Budget

This research uses numerology value of 2 and subscribers spacing value of 30 kHz [20]. Thus, Table 7's parameters are used in the link budget computation for the urban area characteristics.

Table 7. Urban link budget parameters for 5G NSA

Parameters	Uplink	Downlink
Environment	23 dBm	53.8 dBm
Resource block	273	
10 log 10	35.15	
Subcarrier quantity	3276	
gNodeB antenna gain	10 dBi	
gNodeB cable loss	0 dBi	
Penetration loss	22 dBi	
Foliage loss	19.5 dBi	
Body block loss	3 dB	
Interference margin	2 dB	6 dB
Rain/ice margin	0 dB	
Slow fading margin	7 dB	
User terminal antenna gain	0 dB	
Thermal noise power	-153.93 dBm	
User terminal noise figure	3.5 dB	7 dB
Demodulation threshold SINR	-1.1 dB	

4.1.5. Coverage Analysis of the Propagation Model

Next is to determine the amount of gNodeB in Bandung City based on coverage planning aspect. The 3GPP version 38.901 that includes urban propagation model is utilized. The UMa propagation model with outdoor-to-outdoor (O2O) is applied in this study. Thus, the following parameters shown in Table 8 are considered.

Table 8. 5G NSA urban propagation model parameters

Parameters	Uplink	Downlink
Height of base station, hBS	25 m	
Height of user terminal, hUT	1.5 m	
Resultant distance between hBS and hUT, d3D	826.25 m	1412.1 m
Height of equipment, hE	1 m	
Resultant height between the base stations and equipment's heights, h\`BS	24 m	
Resultant height between the user terminal and equipment's heights, h\`UT	0.5 m	
Frequency, fc	3.5 GHz	
Breakpoint distance, d\`BP	560 m	
Cell radius, d2D	825.92 m	1411.89 m
Speed of light, c	$3.0 \cdot 10^8$ m/s	
Path loss, PL	106.1 dB	115.4 dB
Thermal noise power, TN	-153.93 dBm	
Subcarrier quantity, SQ	273	
Coverage area, CA	0.97 km^2	2.84 km^2
Surface area, SArea	167.31 km^2	

4.1.6. Coverage Analysis of Required Amount of gNodeB

The link budget computation and path loss calculation helped to obtain an uplink of 0.79 km^2 and a downlink of 2.84 km^2 for the network design of urban area coverage. The next step is determining the amount of gNodeB in the design area based on two O2O uplink and downlink scenarios. Table 9 presents the amount of gNodeB required.

Table 9. Amount of gNodeB based on coverage approach

Parameters	Uplink	Downlink
Propagation model	UMa LOS O2O	
Surface area	167.31 km^2	
Coverage area	0.97 km^2	2.84 km^2
Amount of gNodeB	172	59

4.1.7. Determining Final Required Amount of gNodeB

In the capacity planning aspect analysis, 86 gNodeB is the required uplink amount of gNodeB and 35 gNodeB is for downlink. These are needed to cover all 3,522,747 populations in the Bandung City area, with 2.18 Gbps/km^2 as the total required network traffic in 2026. Meanwhile, in coverage planning aspect analysis, 172 is the demanded uplink amount of gNodeB and 59 gNodeB is for downlink scenario to cover Bandung City, with an area of 167.31 km^2. Figures 4a and 7b show the required amount of gNodeB results for both the capacity and coverage planning approaches, respectively.

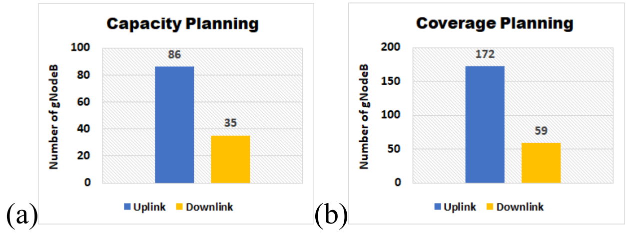

Figure 4. Required amount of gNodeB results: (a) Capacity planning; and (b) Coverage planning

4.2. Simulation Result

The simulation results of SS-RSRP and SS-SINR that are obtained through Forsk Atoll software and will be categorized into several classifications level for determining the KPI qualities. These are shown in the following Figure 5.

	SS-RSRP	SS-SINR
	Sub 6 GHz	Sub 6 GHz
Excellent	≥ -85 dBm	≥ 15 dB
Good	-100 to -85 dBm	10 to 15 dB
Fair	-115 to -100 dBm	5 to 10
Poor	< -115 dBm	< 5 dB

Figure 5. KPI classification level

4.2.1. SS-RSRP

The planned SS-RSRP for Bandung City is shown in Figure 6, while the histogram depiction is presented in Figure 7. Therefore, the average SS-RSRP result of -90.12 dBm is a good value.

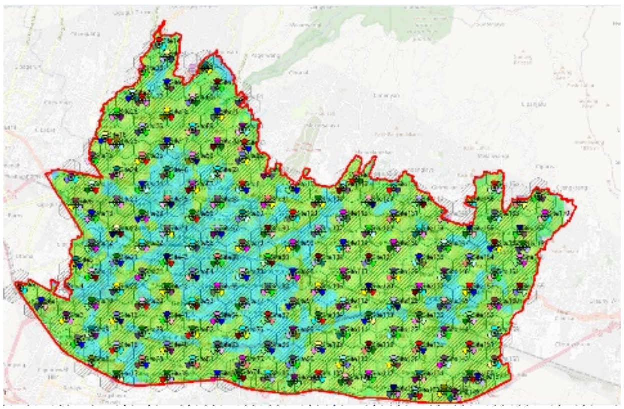

Figure 6. The plotting of gNodeB for SS-RSRP

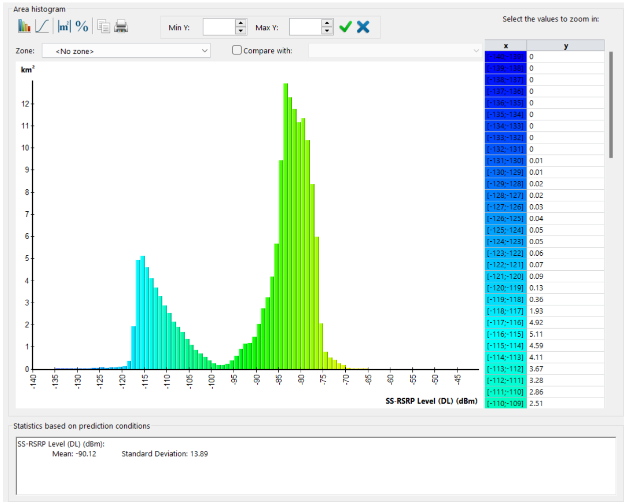

Figure 7. Histogram output of the SS-RSRP

4.2.2. SS-SINR

The planned SS-SINR for Bandung City is shown in Figure 8, while the histogram depiction is depicted in Figure 9. Therefore, the average SS-SINR result of 11.94 dB is a good value.

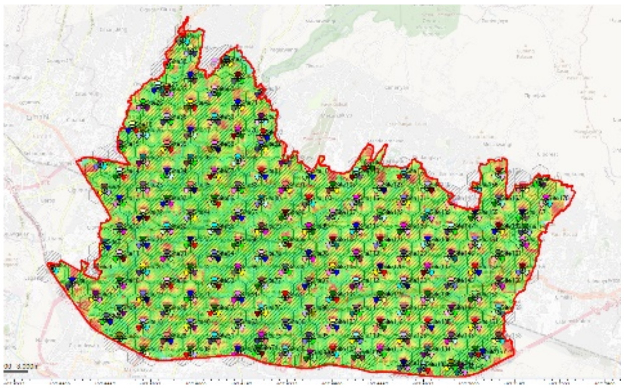

Figure 8. The plotting of gNodeB for SS-SINR

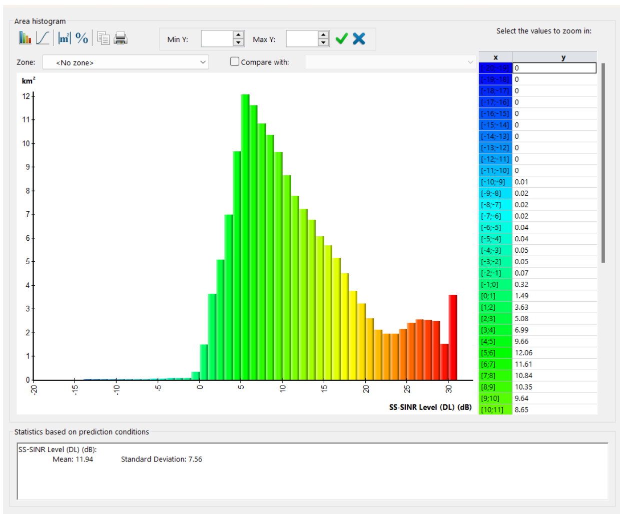

Figure 9. Histogram output of the SS-SINR

4.3. Economic Planning Aspect Analysis

The primary aim of the 5G network design economic analysis is to evaluate the obtained results with economic approaches. The economic viability of 5G technology is assessed through several indicators, such as cost structure (CAPEX and OPEX) and the feasibility indicator parameters (NPV, IRR, PBP, and PI). In addition to analyzing economic feasibility, this research also analyzed indicators of economic feasibility by identifying parameters that significantly impact the changes through the sensitivity analysis method. The economic analysis was carried out to implement 5G technology in the Bandung City area from 2021 until 2026.

4.3.1. Cost Structure Analysis

CAPEX and OPEX make up the cost structures. CAPEX is a business expense or capital cost incurred as an initial investment to add assets or develop a business infrastructure. Hardware, software services, and other requirements contribute to the total cost of CAPEX in 5G network infrastructure. The hardware and software pricing models are based on Indonesian vendors' prices. Table 10 illustrates the CAPEX requirements for implementing 5G networks in Bandung to get CAPEX values from 2021 to 2026. The CAPEX was only calculated at the start of the implementation year in this study. This is because there are initial costs for the 5G 3.5 GHz project, and there is no new gNodeB added in the following year; the amount of gNodeB remains at 172.

Table 10. CAPEX's requirements

Item	Price
Baseband unit	$328,630.08
Remote radio unit	$596,461.60
Antenna sectoral for macro	$249,104.16
Combiner	$39,145.48
Installation fee	$116,826.52
Additional rectifier	$17,793.40
Supporting material	$48,634.72
Equipment	$85,406.60
Software and licenses	$537,598.04
Total CAPEX	**$2,019,600.60**

Meanwhile, OPEX is an expense associated with the company's everyday operational activities. Therefore, the calculation of OPEX costs was influenced by the demanded amount of gNodeB, the amount of 5G subscribers, the power consumption, and the license fees [11]. This study calculated OPEX from the start of the implementation year until the end of the next five years and is shown in Table 11.

Table 11. OPEX's requirements

Year	Total OPEX
N (0) – 2020	$11,508,763.75
N (1) – 2021	$11,873,490.70
N (2) – 2022	$12,414,496.40
N (3) – 2023	$13,090,313.24
N (4) – 2024	$13,897,333.27
N (5) – 2025	$15,412,366.91

4.3.2. Economic Feasibility Analysis

Economic feasibility in this study aims to explore how the project should be implemented. To support feasibility analysis calculations, some supporting assumptions are considered. Like the interest rate of 15%, this amount is taken based on usage for telecommunication projects in Indonesia.

4.3.2.1. NPV Analysis

NPV is obtained when the present values of the cash inflows and cash outflow are deducted over a period. A business is financially viable if its NPV is positive. However, the business is deemed infeasible if the NPV is negative. Therefore, the NPV value is one of the crucial parameters used to assess a project or effort, whether feasible or not. CAPEX and OPEX data per year are essential for performing parameter analysis. Table 12 shows the annual NPV generated from the 5G deployment business in Bandung City.

Table 12. Total cost and revenue for NPV projection

Year	Cash outflow		Cash inflow	Net cash	Present value
	CAPEX	OPEX			
0	$2,019,598.51	$11,143,956.15	$0.00	-$13,163,554.66	-$11,143,956.15
1		$11,873,490.70	$6,833,703.72	-$6,551,723.07	-$17,695,679.22
2		$12,414,496.40	$11,889,831.72	-$682,064.08	-$17,763,743.3
3		$13,090,313.24	$18,205,876.97	$6,650,232.85	-$11,113,510.45
4		$13,897,333.27	$25,748,120.28	$15,406,023.10	$4,292,512.65
5		$15,412,366.91	$34,284,423.72	$18,872,056.8	$23,164.569.45

In Table 12, the present value is always positive, starting from the fourth year (2025) of $4,292,512.65. From the income, discount rate, and the present value of the data above, the total NPV can be calculated. The NPV value is created from the previous year, according to the modeling time span.

NPV= \$2,019,698.51+(-\$13,163,554.66/ (1+0.15)^0) +(- \$6,551,723.07/(1+0.15)^1)+(-\$ 682,064.08/(1+ 0.15)^2)+(\$ 6,650,232.85/(1+0.15)^3)+(\$5,406,023. 10/(1+0.15)^4)+(\$ 18,872,056.8/(1+0,15)^5) = \$ 5,219,311.44

The calculation of NPV with a discount rate of 15% produces an NPV value of \$ 5,219,311.44. BEP is reached in the 4 years. In this case, 5G can be considered a worthy investment for cellular operators. Thus, the 5G deployment in Bandung can be concluded as a feasible project based on the NPV parameters.

4.3.2.2. IRR Analysis

IRR analysis is an interest rate value used to measure the level of investment to produce NPV (Net Present Value) equal to 0 (initial investment). From an IRR point of view, a business is said to be viable if the IRR> interest rate and not feasible if the IRR < interest rate. Parameter IRR is also used to assess whether a project is feasible or not. In this study, the IRR produced 23.13%. To find the NPV value equal to zero if the discount rate has a value of 15%. Thus, the 5G organizing project in Bandung can be considered viable from the perspective of IRR parameters because the resulting IRR value is higher than the determination of the discount rate of 8.13%. Figure 10 shows the presentation of IRR 5G with an IRR value of 23.13%.

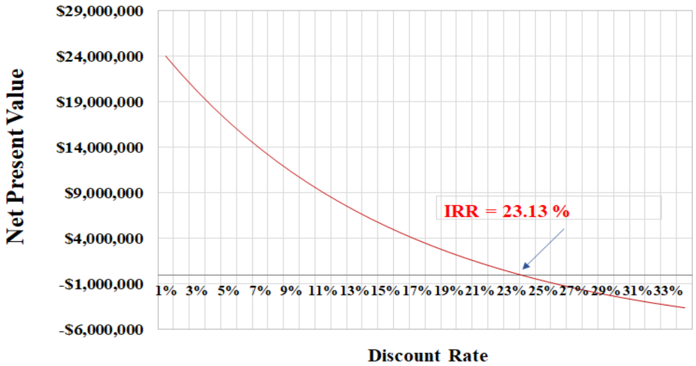

Figure 10. IRR discount rate value

4.3.2.3. PBP Analysis

PBP is the time it takes for cellular operators to return capital (break-even) from infrastructure development at the beginning of the investment. This study uses cumulative Net Cash Flow (NCF) to determine the payback period. The PBP will be in the ninth year when cumulative NCF indicates the 0 number in a given year in the business cycle. Figure 11 presents the PBP, which shows break event point 5G with the position of BEP between the third and fourth years. To get a cumulative NCF value of \$0, the time needed is 4 years and 3 months.

Estimates the return on capital on 5G by dividing the rest of the 3rd year by the 4th year of cash. So, achieving the break-even point of 5G investment takes 3 years and 10 months. The feasibility measurement assumes that 5G implementation is feasible when the BEP is completed in less than 5 years of mobile infrastructure utilization. In that case, the infrastructure target must be 2.5 years since infrastructure development began. Thus, the 5G deployment in Bandung City can be concluded as a viable project based on the PBP parameter.

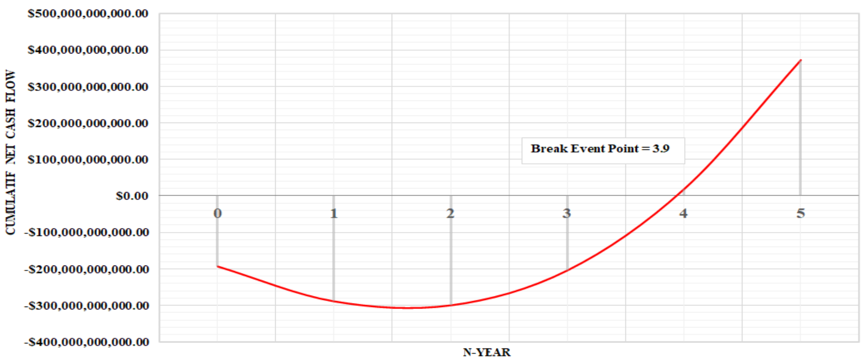

Figure 11. Cumulative NCF that represents the BEP.

4.3.2.4. PI Analysis

PI is a benefit/cost ratio representing the value of cash inflows and cash outflows from a business. In business, a project will be more exciting and worth continuing if there is a higher PI value. In this study, PI was 1.11. This means that the business is considered feasible because the PI value is greater than 1. Thus, the 5G deployment in Bandung City can be concluded as a viable project and can be continued based on the PI parameter.

4.3.3. Economic Feasibility Analysis Assessment

In business analysis, the design of the 5G network in Bandung is feasible. The feasibility value of the indicator in this study is shown in Table 13.

Table 13. Feasibility indicators for economic analysis

NPV		IRR		PBP		PI		Category
≥ 0	F	≥ 15%	F	≤ 5 years	F	≥ 1	F	Feasible (F)
< 0	N	< 15%	N	> 5 years	N	< 1	N	Not feasible (N)

Meanwhile, the results of the business feasibility test of the 5G deployment with the baseline scenario are shown in Table 14.

Table 14. Feasibility analysis results (baseline scenario)

Feasibility Indicator	Value	Conclusion
NPV	$5,219,311.34	Feasible
IRR	23.13%	Feasible
PBP	3 years and 10 months	Feasible
PI	1.11	Feasible

4.3.4. Sensitivity Analysis

In this study, sensitivity analysis was used to identify parameters that significantly impact the viability of the 5G implementation business with the scenario shown in Table 15. These three sensitivity analysis scenarios describe the business's advantages and disadvantages under what conditions. The baseline scenario follows standard research assumptions. The optimistic and pessimistic scenarios represent sensitivity analyses in which parameter values are varied up or down compared to the baseline to evaluate the impacts on the 5G business case.

Table 15. Sensitivity analysis scenarios and impact

Scenario	Parameters impact
Pessimistic	-10 % of the baseline
Baseline	0%
Optimistic	+10% of the baseline

The threshold scenario aims to determine the minimum percentage of baseline parameter values that allows the 5G business model to remain economically viable, as indicated by an NPV of 0. To reach the threshold, technical and economic parameters from the baseline scenario are systematically reduced until the minimum combination of parameters that sustains viability is identified. Those parameters are:

4.3.4.1. CAPEX

In the 5G business sensitivity analysis, CAPEX is one of the influential parameters in business viability. Table 16 shows the impact of changes in CAPEX addition and subtraction parameters on the business feasibility of each scenario. Some of the essential points gained from the sensitivity analysis for CAPEX parameters are as follows:

Table 16. Impact of CAPEX

CAPEX	Threshold	Pessimistic	Baseline	Optimistic
	397.2%	-10%	0%	+10%
NPV	≈ 0	$5,394,928.60	$5,219,311.34	$5,043,694
IRR	≈ 15%	23.46%	23.13%	22.80%
PBP	4 years 3 months	3 years 8 months	3 years 10 months	3 years 9 months
PI	≈ 1	1.12	1.11	1.11

- In the pessimistic scenario with values 10% below the baseline, the PBP is faster than the baseline and threshold scenarios at three years and eight months. The NPV obtained is $5,394,928,60 with an IRR of 23.46%, and a PI of 1.12 exceeding baseline and threshold. Despite the pessimistic capital expenditure assumptions, investment viability is maintained.
- In the optimistic scenario with values 10% above baseline, the PBP is similar to the baseline but less than the threshold scenario at three years and nine months. The NPV is $5,043,694 with an IRR of 22.80%. The PI matches the baseline, so despite the optimistic capital expenditure assumptions, investment viability is maintained.

4.3.4.2. Number of Subscribers

In the 5G business sensitivity analysis, one of the influential parameters is the number of subscribers. Table 17 shows the business impact caused by changes in the parameters of adding and subtracting the number of 5G users to the business scenarios. Some crucial points obtained from sensitivity analysis for the number of subscribers parameter are as follows:

Table 17. Impact of subscribers' numbers

Number of subs	Threshold 91.14%	Pessimistic -10%	Baseline 0%	Optimistic +10%
NPV	≈ 0	-$669,619.82	$5,219,311.3	$11,108,242.5
IRR	≈ 15%	14%	23.13%	32%
PBP	4 years 3 months	4 years 4 months	3 years 10 months	3 years 5 months
PI	≈ 1	0.99	1.11	1.25

- In the pessimistic scenario, with values 10% below baseline, the PBP exceeded the baseline and threshold by four years and four months. The NPV was -$669,619.8 with a 14% IRR. The PI was 0.99, below baseline and threshold. Thus, the pessimistic subscriber numbers do not demonstrate business feasibility.
- In the optimistic scenario, with values 10% above baseline, the PBP was achieved more rapidly versus baseline and threshold, with full cost recovery in three years and five months. The NPV was $11,108,242.5 with a 32% IRR. The PI exceeded baseline and threshold at 1.25. Thus, the optimistic subscriber numbers demonstrate the feasibility of the business.

4.3.4.3. Amount of gNodeB

In the 5G business sensitivity analysis, the amount of gNodeB is one of the influential parameters in business viability. Table 18 shows the business impact caused by changes in parameters to increase the amount of gNodeB to the number of scenarios. Some critical points obtained from the sensitivity analysis for the amount of gNodeB are as follows:

Table 18. Impact of the amount of gNodeB

Amount of gNodeB	Threshold 104.93%	Pessimistic -10%	Baseline 0%	Optimistic +10%
NPV	≈ 0	$15,069,070.9	$5,219,311.3	-$5,628,927.5
IRR	≈ 15%	42%	23.13%	7%
PBP	4 years 3 months	3 years 1 month	3 years 10 months	4 years 6 months
PI	≈ 1	1.42	1.11	0.90

- In the pessimistic gNodeB scenario, with a 10% reduction to 155 gNodeBs, the PBP was achieved faster than baseline and threshold, within three years and one month. The NPV was $15,069,070.9 with a 42% IRR. The PI was 1.42. Thus, the pessimistic gNodeB parameters demonstrate business feasibility.
- In the optimistic gNodeB scenario, with a 10% increase to 189 gNodeBs, the PBP was longer versus baseline and threshold at four years and six months. The NPV was -$5,628,927.5 with a 7% IRR. The PI was 0.90, below baseline and threshold. Thus, the optimistic gNodeB parameters do not demonstrate business feasibility.

4.3.4.4. Marketing Cost

In the 5G business sensitivity analysis, marketing cost is one of the parameters influencing business viability. Table 19 shows the business impact caused by changes in marketing cost addition and reduction parameters on the business of each scenario. Some essential points obtained from sensitivity analysis for marketing cost parameters are as follows:

Table 19. Impact of marketing cost

Marketing cost	Threshold 173.55%	Pessimistic -10%	Baseline 0%	Optimistic +10%
NPV	≈ 0	$5,928,968.3	$5,219,311.3	$4,509,654.3
IRR	≈ 15%	24%	23.13%	22%
PBP	4 years 3 months	3 years 8 months	3 years 10 months	4 years
PI	≈ 1	1.13	1.11	1.10

- In the pessimistic scenario, which projects values 10% smaller than the baseline scenario, the PBP is achieved more rapidly than in the baseline scenario, occurring within three years and eight months. Consequently, the NPV attained in this pessimistic scenario is $5,928,968.3, with an IRR of 24%. Moreover, the PI exceeds that of both the baseline and threshold scenarios, reaching 1.13. Therefore, the marketing cost parameters for the pessimistic scenario satisfy the feasibility criteria for the business.
- In the optimistic scenario, which projects values 10% greater than the baseline scenario, the PBP is achieved more slowly than in the baseline scenario yet faster than in the threshold scenario, occurring within four years. Consequently, the NPV attained in this optimistic scenario is $4,509,654.3, with an IRR of 22%. Moreover, the PI is not much different from that of the baseline and threshold scenarios, reaching 1.10. Therefore, the marketing cost parameters for the optimistic scenario still satisfy the feasibility criteria for the business.

4.3.4.5. Operation & Maintenance Cost

In the 5G business sensitivity analysis, one of the parameters that influence business viability is operational and maintenance cost.

Table 20 shows the business impact caused by changes in operational and maintenance cost addition and reduction parameters to the number of scenarios. Some crucial points obtained from sensitivity analysis for operating and marketing cost parameters are as follows:

Table 20. Impact of operation and maintenance cost

O & M cost	Threshold 110.46%	Pessimistic -10%	Baseline 0%	Optimistic +10%
NPV	≈ 0	$10,211,707.5	$5,219,311.3	$226,915.1
IRR	≈ 15%	32%	23.13%	15.4%
PBP	4 years 3 months	3 years 5 months	3 years 10 months	4 years 2 months
PI	≈ 1	1.25	1.11	1.00

- Under the pessimistic scenario, which is 10% below the baseline assumptions, the PBP is achieved more rapidly compared to the baseline and threshold scenarios, at three years and five months. Despite the pessimistic inputs, the NPV obtained is $10,211,707.5 with an IRR of 32%, and the PI exceeds that of the baseline and threshold cases at 1.25. Given these investment metrics, the pessimistic operational and maintenance cost parameters still result in a financially feasible business model.
- In the optimistic scenario with values 10% above the baseline, the PBP is longer than in the baseline but faster than the threshold scenario at four years and two months. The NPV obtained is $226,915.1 with an IRR of 15.4%, and a PI of 1.00 which is lower than baseline. Despite the extended PBP, the optimistic operational and maintenance cost parameters still result in a financially feasible business case.

4.3.5. Sensitivity Analysis in Spider Web Representation

The analysis based on the sensitivity will present how business viability affects various changes in the value of each parameter. Figure 12 shows a spider web for sensitivity analysis in 5G business organizing.

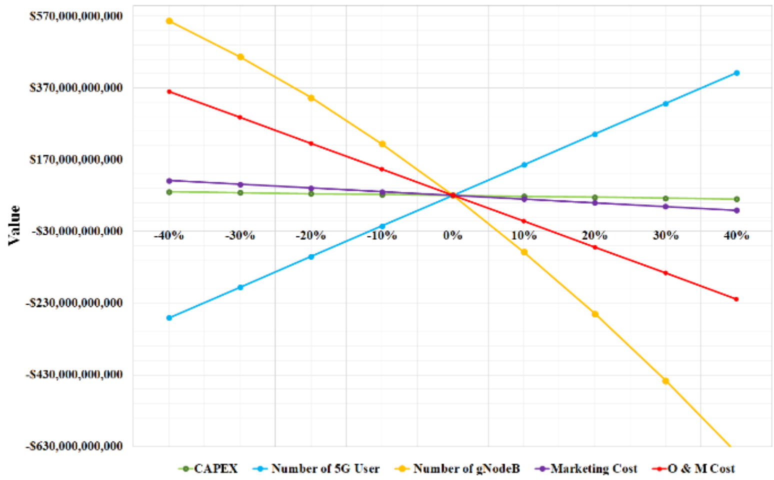

Figure 12. Spider web representation of impactful parameters in a sensitivity analysis.

From the presented Figure 11, this study found that CAPEX and marketing costs are the most minor impact parameters in deploying 5G in an urban area, each affecting less than $10,000,000. Meanwhile, the 5G subscribers and the amount of gNodeB are the most impactful parameters, with 5G subscribers in an optimistic scenario presenting the most significant increase in positive NPV since there is an increase in the number of subscribers and therefore, the business will obtain more revenue. Following that, parameter of the amount of gNodeB shows the most significant decrease of NPV since the business deployed more gNodeB than the optimal requirement and thus makes the business reach its PBP longer.

5. Conclusion

The technical and business sensitivity analyses demonstrate the feasibility of deploying a 5G NSA network operating at 3.5 GHz in Bandung City, Indonesia. The demanded capacity is estimated at 2.18 Gbps/km^2, necessitating 172 gNodeBs with 0.79 km^2 coverage areas. Simulation results confirm good signal strength (SS-RSRP -90.12 dBm) and signal quality (SS-SINR 11.94 dB) for its subscribers. The 5G business case yields positive returns, with NPV of $5.2 million in 2026, PBP under four years, IRR of 23.13%, and PI of 1.11.

Then, the sensitivity analysis identifies CAPEX, subscriber numbers, amount of gNodeBs, marketing expenses, and O&M costs as key value drivers. In particular, the quantity of gNodeBs significantly influences the project economics of 5G NSA network deployment. Further research could investigate the 5G techno-economics in suburban and rural regions, various 5G use cases like mMTC and uRLLC, or additional spectrum bands beyond 3.5 GHz. Overall, research findings indicate that deploying a 5G NSA network at 3.5 GHz in Bandung City is technically feasible and financially attractive as the initiative offers substantial value, meriting consideration for implementation for Indonesian operators.

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