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Techno-Economic Assessment of 5G NSA Deployment for Metropolitan Area: A Greenfield Operator Scenario

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Abstract—Indonesia is the fourth-most populous country, with 260 million people. This increases telecom network demand. 4G-LTE is Indonesia's lea ding mobile technology (LTE), but its network is now crowded. The telecom business must adjust to consumer mobility and growing demand. The Indonesian government urges the deployment of 5G New Radio (NR) with Non-Stand Alone (NSA) model in 13 Indonesian cities area, especially in the capital city of Jakarta, which is the economic and government center of Indonesia. This research attempts to determine the technological and economic plans needed to satisfy the 5G NR mid-band 3.5 GHz with the NSA model for both capacity and coverage needs in a metropolitan and dense-urban area of Indonesia, Jakarta City. This research utilized mid-band 3.5 GHz frequency due to its ability to hold optimum capacity and coverage, especially for greenfield operator scenarios (new mobile operators). According to analysis, all Jakarta municipals will need 919 5G NR 3.5 GHz gNodeB and create 17.7 Gbps/km^2 of traffic. Synchronization Signal-Reference Signal Received Power (SS-RSRP) averages -93.27 dBm and is rated good, while SS-SINR averages 8.89 dB and is considered fair. In terms of economics, total CAPEX is IDR 147,184,134,855, total OPEX is IDR 1,004,463,403,900, Net Present Value (NPV) is IDR 477,532,953,385, Internal Rate of Return (IRR) is 24.7%, Payback Period (PBP) is 3.87 or within three years and ten months, and Profitability Index (PI) is 1.42. Meanwhile, the results of the sensitivity analysis indicates that the number of gNodeB and the number of users are the most significant parameters that greatly affect the business feasibility of deploying 5G NR NSA with 3.5 GHz in the metropolitan area of Jakarta City.

Index Terms—5G, dense-urban, Jakarta City, network deployment, techno-economic, telecom management

I. Introduction

Indonesia and the rest of the world have seen tremendous advancements in cellular telecommunications technology. Because of this, consumers' demand for data access speed and quota has skyrocketed. Creating a 3G Wideband Code Division Multiple Access (WCDMA) communication network in Indonesia's cellular broadband development is an early achievement stage [1]. Despite this, 3G network deployment is not the end of the journey. Indonesian telecommunication companies are developing a fifth generation (5G) New Radio (NR) network to succeed the current 4G Long Term Evolution (LTE) network. Currently, telecommunication operators are deploying the 4G LTE network in all major cities in Indonesia.

Meanwhile, the claimed 5G NR network implemented in Jakarta City uses the 4G LTE network infrastructure. Therefore, it has not reached the supposed full capability of a 5G network, known as 5G NR Non-Stand Alone (NSA). However, despite the challenges, the Indonesian Ministry of Communications, and Information Technology (KOMINFO) is confident that by 2025, the entire major cities will be covered by a 5G NR network [2]. The 5G NR technology is the most recent and advanced, following its predecessor, 4G LTE. In addition, it includes several revolutionary innovations, as illustrated in Fig. 1 [3].

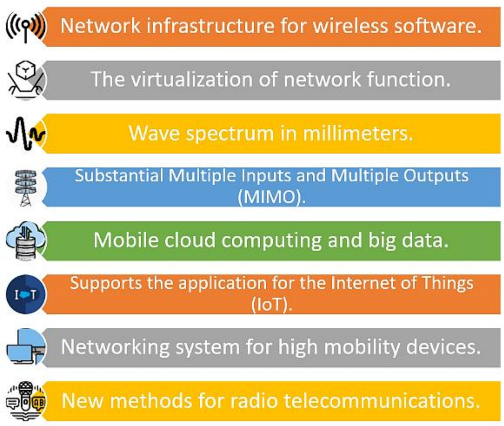

Fig. 1. Revolutionary innovations of 5G technology.

Previously, several kinds of research have been conducted for 5G network implementation in Indonesia. For example, a network dimensioning assessment of the 5G network in Jakarta [4]. Then, another exploration of 5G network evaluations in Bandung City, both in 3.5 GHz and 28 GHz [5]-[6]. Lastly, the study of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for the 5G network in a residential area Citra

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Raya Cikupa, located in Tangerang, Indonesia [7]. Thus, none of the previous research studies a complete techno-economic analysis of the 5G NR network. Therefore, this research aims to provide a techno-economic apprsoach for implementing a 5G network with NSA architecture, utilizing a 3.5 GHz mid-band and a bandwidth of 100 MHz for new greenfield operators that want to deploy 5G NR in a dense urban Jakarta City.

Section I introduces this research, while Section II covers the 5G network and feasibility study in detail. This study's methodology is detailed in Section III. Finally, Section IV discusses the results and analyses of the Atoll software's prediction simulations and feasibility studies, and Section V concludes the research for this paper.

II. 5G NR Technology

A. 5G Cellular Networks

The fifth-generation telecommunications technology represents a leap forward compared to prior generations. For instance, Fig. 2 depicts the evolution of telecommunications technology, beginning with analog voice, progressing to digital with messaging features and finally to 5G technology. The 5G technology has six characteristics that make it better than its predecessor. For example, it has a peak data rate of at least 10 Gbps, providing spectral efficiency of 120 b/s/Hz, and accommodating a higher range of frequency bands up to 300 GHz. Furthermore, it also has an exceptionally low latency of 1 ms, supports high mobility (500 km/h) while maintaining a satisfactory level of Quality of Service (QoS), and provides connection densities of up to 106 connections per km^2.

B. The Architecture of 5G

The entire architecture of the 5G NR is seen in Fig. 3. This is in accordance with the 3rd Generation Partnership Program Technical Specification (3GPP TS) 38.300, which lays out the requirements for the technology. As seen in the diagram, the gNodeB node delivers NR user plane and control plane protocol terminations to the User Equipment (UE), such as the 5G terminal devices (e.g., smartphone, tablet, or laptop). It is connected to the 5G Core (5GC) via the NG interface [8].

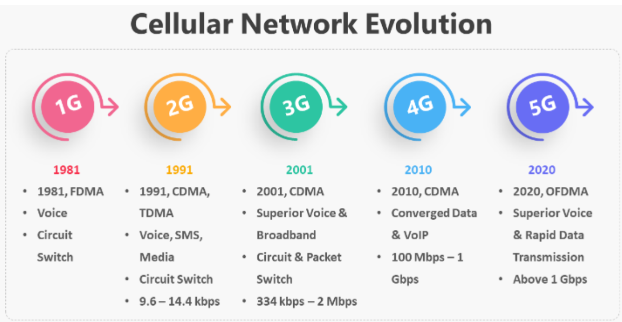

Fig. 2. The evolution of cellular technology.

The network architecture of 5GC is very versatile, configurable, and deployable. It provides several features, including network slicing, to meet the diverse needs of customers. In addition, it provides distributed cloud, Network Functions Virtualization (NFV), and Software-Defined Networking (SDN).

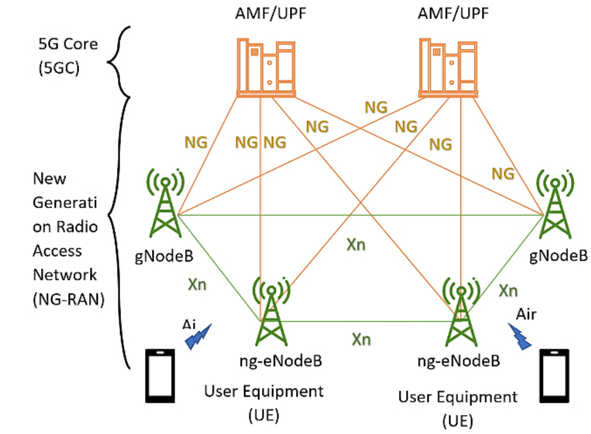

Fig. 3. The architecture of 5G NR as per 3GPP TS 38.300.

C. 5G NSA Deployment Model

5G NSA implies that the existing 4G infrastructure will support the 5G network. Here, 5G-enabled smartphones will connect to 5G radio frequencies for faster data throughput but still use 4 G's core network. The NSA is heavily regulated in 3GPP release 15. In the initial rollout of the NSA infrastructure, 5G will focus on improving mobile broadband to provide increased data bandwidth and connection reliability through two new 5G radio frequency allocation ranges, Frequency Range 1 (FR 1) and Frequency Range 2 (FR 2).

D. 5G Use Cases and Services

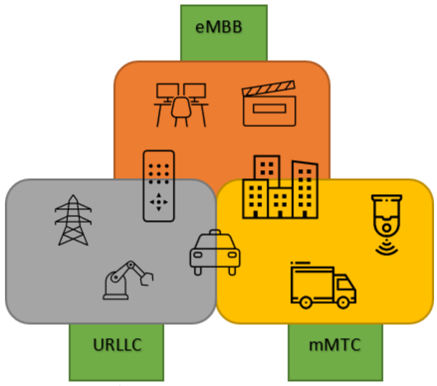

Fig. 4. Usage scenarios for 5G technology.

5G technology has significantly greater technological capabilities than 4G LTE. This directly impacts the services that can be provided and the increasing variety of use cases. The services that the 5G network is capable of supporting are classified into three categories, as shown in Fig. 4 [9], and are described as follows:

- Massive Machine Type Communications (mMTC): The mMTC use case demands the network to accommodate billions of low-cost, low-power devices.
- Enhanced Mobile Broadband (eMBB): 5G technology is anticipated to provide high

connections and mobility, with peak data rates up to 20 Gbps.
- Ultra-Reliability, Low Latency Communication (URLLC): This technology is used for various applications that require excellent reliability and latency, greater real-time responsiveness, and higher data security, such as self-driving automobiles.

E. Techno-Economic Analysis (TEA)

Technical and economic inputs forecast capital, operating, and income demands. It provides a framework for investment decisions and proposals to increase the user's value proposition [10]. This research splits technology into capacity and coverage. Capacity anticipated 5G users, traffic demand, and throughput. The coverage approach calculated 5G coverage. Fig. 5 depicts 5G network planning for capacity and coverage. The economic side consists of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). The business feasibility consists of Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Profitability Index (PI). A spider diagram with thresholds is used for business sensitivity.

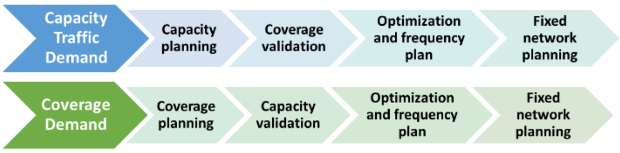

Fig. 5. Network planning based on capacity and coverage.

F. Jakarta City's Geographic

The location object for this thesis is Indonesia's economic hub, namely Jakarta City, which was classified previously as congested. To better understand the modeling domain, this thesis uses data from the Central Statistics Agency (BPS) [11]. The data will then be utilized to forecast values relating to the demography of Jakarta City, shown in Fig. 6. Jakarta is a city on the Indonesian island of Java that serves as the country's economic core and has a total surface area of 662.33 km^2 [12].

Fig. 6. Geographic maps of Jakarta City [12].

According to the statistics [11], the city of Jakarta is divided into six areas: North Jakarta, East Jakarta, South Jakarta, West Jakarta, Central Jakarta, and the Thousand Islands (administrative region). The composition of the surface area of each city in the Jakarta area and its population are shown in Table I. East Jakarta is the city's most populous and most vast district. According to the same data, around 661,018 were aged between 0 and 4.

TABLE I: NUMBER OF POPULATION LIVING IN JAKARTA CITY

City/Municipals	Surface area (km^2)	Number of populations
North Jakarta	146.66	1,812,915
East Jakarta	188.03	2,937,859
South Jakarta	141.27	2,264,699
West Jakarta	129.54	2,589,933
Central Jakarta	48.13	928,109
Thousand Islands	8.7	24,295
Total	662.33	10,557,810

G. 5G Key Performance Indicator (KPI)

KPIs are crucial performance indicators that help achieve expected results. This study uses KPI to evaluate the 5G NR network's performance, namely, Synchronization Signal Reference Signal Received Power (SS-RSRP) and Synchronization Signal of Signal-to-Interference Noise Ratio (SS-SINR) determine the 5G NR network performance [13]. Table II displays 5G NR sub-6 GHz and sub-1 GHz KPI ranges.

TABLE II: RANGE OF VALUES FOR 5G NR KPI

Range	(-157.00 to 30.00) SS-RSRP (dBm)		(-23.5 to 40.00) SS-SINR (dB)	
	Sub 6 GHz	Sub 1 GHz	Sub 6 GHz	Sub 1 GHz
Excellent	>= -85	>= -80	>= 15	>= 15
Good	-100 to -85	-95 to -80	10 to 15	10 to 15
Fair	-115 to -100	-115 to -95	5 to 10	5 to 10
Poor	<-115	<-115	<5	<5

III. RESEARCH METHODOLOGY

A. System Design

Fig. 7 shows the 5G network planning research framework. First, acquire data such as the population, area, and population density that affect the geographic type conditions. The subsequent step involves planning a capacity and coverage approach such as forecasting subscriber numbers, traffic demand over the network deployment range, the capacity of soon-to-be-deployed technology, and the 5G network deployment pricing model. Finally, technology usage determines coverage planning, including frequency, modulation, power, other technical characteristics, and cell radius utilized to compute the covered area

Next, the deployment strategy compares coverage and capacity demand to determine the required number of Jakarta sites.

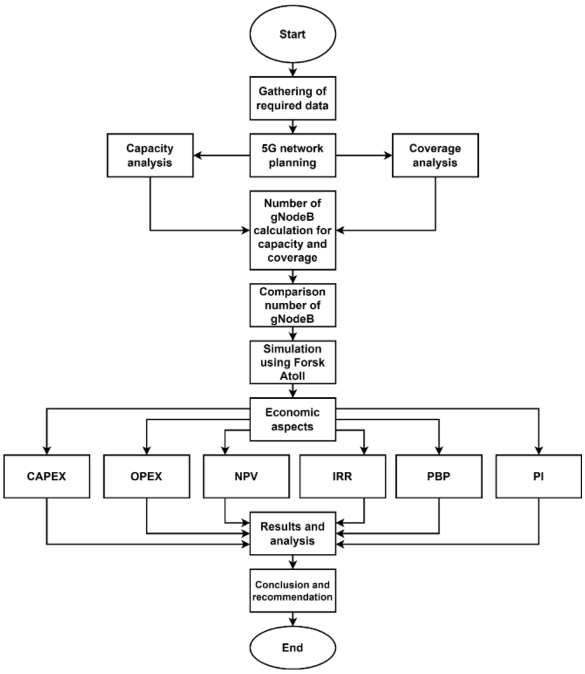

Fig. 7. 5G NR deployment research framework.

1) Collecting data

First, we collected the 5G reference data. BPS Jakarta's 2020 report [11] provided geographic type segmentation data. A deeper study led to 5G customer forecasting models such as the estimated data, traffic, and coverage needs. Based on many experiments, this research engages 5G technology [2] [4] [5]. 5G concepts include frequency spectrum, modulation, and ITU-required bandwidth [14]. This study also examines 5G ITU-compliant documents and deployment costs. Books, papers, and a telecom company's internal database provide economic data.

2) Capacity method

The process of preparing for anticipated services, such as the traffic demand and throughput calculations, is included in the capacity approach [6]. Other affecting variables are:

i) Market Users' Prediction:

User predictions can affect capacity plan needs. This research's market users' and market capacity projections employ the Bass model, which is presented in equation (1), as in [15]

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

where,

$N\,(t)$ = number of market users,
M = capacity for the dense-urban area market,
$p > 0$ = the innovation coefficient,
$q \geq 0$ = the imitation coefficient.

ii) Traffic Demand Forecasting:

According to mobile traffic demand, network performance density per kilometer will be determined by the number of users per km^2. Finding the needs in traffic by using the equation (2), as in [16]

$$G\,(t) = \rho \cdot \frac{8}{N_{dh} \cdot N_{md}} \cdot \frac{1}{3600}\,\varphi\,(t) \cdot D_k \quad (2)$$

where,

$G\,(t) =$ the traffic demand forecast,
$\rho =$ the population density within an area,
N_{dh} = busy hour per day,
N_{md} = days in a month,
$\varphi\,(t) =$ maximum percentage of active users, in this research is 100%,
D_k = monthly average traffic request demand.

iii) Throughput in Uplink and Downlink:

The fifth generation has an uplink/downlink ratio of 10/20 Gbps. It is also supported for operator band combinations. Equation (3) is utilized to determine the 5G NR uplink/downlink throughput, as in [17]

$$Throughput_{data\ rate} = 10^{-6} \cdot \sum_{j=1}^{j}\left[V_{layers}^{j} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu}}{T_s^{\mu}} \cdot 12 \cdot \left(1 - OH^{(j)}\right)\right]. \quad (3)$$

where,

$j =$ number of component suppliers aggregated within a single band,
V_{layers}^{j} = max layers,
$Q_m^{(j)}$ = maximum modulation order,
$f^{(j)}$ = factor for scaling,
R_{max} = 948/1024,
μ = research numerology.
$N_{PRB}^{BW(j),\mu}$ = maximum bandwidth allocation for a resource block,
T_s^{μ} = mean length of μ subframe's OFDM,
$BW\ (j)$ = bandwidth,
$OH^{(j)}$ = overhead value.

3) Coverage method

The gNodeB is needed for coverage planning in Jakarta's 5G NR network implementation. Therefore, many variables must be calculated to get gNodeB, such as:

i) Link Budget:

The link budget calculates the loss of signal strength between the site and the user terminal, as illustrated in Fig. 8. The gNodeB link budget is specified for Key Performance Indicators (KPI). 5G link budget calculations are similar to 4G budget calculations. 5G includes body block, foliage, and rain or snow. Standard 3GPP 38.901 Urban Macro (UMa) path loss propagation equation (4) is utilized, as in [18]

$$\begin{gathered} Path\ loss\ (dB) = \\ gNodeB\ transmit\ power\ (dBm) - 10 \cdot \\ log10\ (subcarrier\ quantity) + \\ gNodeB\ antenna\ gain\ (dBi) - \\ gNodeB\ cable\ loss\ (dB) - \\ penetration\ loss\ (dB) - foliage\ loss\ (dB) - \\ body\ block\ loss\ (dB) - \\ interference\ margin\ (dB) - \\ rain\ or\ snow\ margin\ (dB) - \\ slow\ fading\ margin\ (dB) + \\ UE\ antenna\ gain\ (dB) - \\ thermal\ noise\ power\ (dBm) - \end{gathered}$$

$$UE\ noise\ figure\ (dB) - demodulation\ threshold\ SINR\ (dB). \quad (4)$$

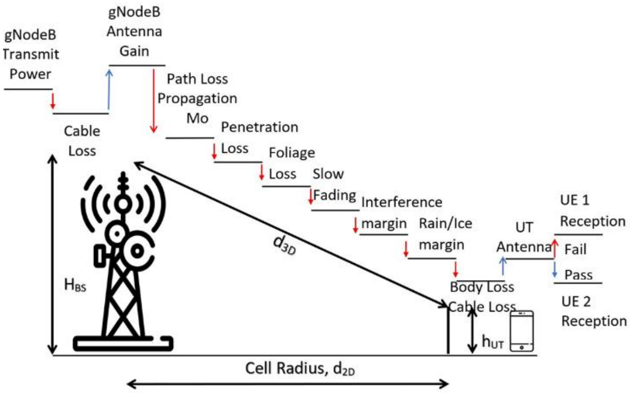

Fig. 8. 5G NR link budget illustration.

ii) Additional Loss in 5G Network:

5G NR mid-band losses at 3.5 GHz and 100 MHz are projected. In body block loss, 5G mid-band frequency is higher than 4G LTE but has a shorter range. Body block loss is formed when any object gets closer to the user. Additional losses are listed in Table III [17].

TABLE III: THE PARAMETERS FOR ADDITIONAL LOSSES IN 5G NR NETWORK

Classification	Parameters
Type of area	Dense-urban
Frequency	3.5 GHz
Penetration loss	28 dB
Foliage loss	7.5 dB
Body block loss	3 dB
Interference margin	UL = 2 dB DL = 17 DB
Rain/ice margin	0 dB
Slow fading margin	8 dB

iii) Model of Propagation:

5G's propagation model differs from older technologies. 5G uses 3GPP propagation model 38.901 with UMa, Rma, and UMi conditions. In this research, the 3GPP 38.901 UMa LOS model of propagation is shown in the equations (5 -7), as in [19]

$$Path\ loss_{UMa-LOS} = 28.0 + 30\log(d_{3D}) + 20\log(f_c) - 9\log[(d'_{BP})^2 + (h_{BS} - h_{UT})^2] \quad (5)$$

$$d_{2D} = \sqrt{{d_{3D}}^2 - (h_{BS} - h_{UT})^2} \quad (6)$$

$$d'_{BP} = 4 \cdot h'_{BS} \cdot h'_{UT} \cdot \frac{f_c}{c} \quad . \quad (7)$$

where,

$Path\ loss_{UMa-LOS}$ = path loss Uma LOS (dB),
d_{3D} = hBS and hUT resultant distance (m),
h_{BS} = height of base station (m),
h_{UT} = height of user terminal (m),
f_c = frequency used for carrier (Hz),
d'_{BP} = distance for breakpoint (m),
d_{2D} = radius of the cell (m),
c = speed of light (m/s),
h'_{BS} = height of base station (m) – the height of equipment (m),
h'_{UT} = height of user terminal (m) – the height of equipment (m).

Meanwhile, the maximum site coverage is used for link budget coverage projections. The equation (8) calculates each site's coverage area, as in

$$Coverage\ area = 1.95 \cdot (d_{2D})^2. \quad (8)$$

iv) Dense Urban gNodeB Parameters:

In this research, the frequency used is 3.5 GHz with 100 MHz bandwidth, and the transmit power is 49 dBm. Table IV illustrates gNodeB parameter values in a dense urban area.

TABLE IV: DENSE URBAN AREA PARAMETERS

Parameters	Value
Transmitter power	49 dBm
Antenna's gain	2 dBi
Antenna's height	30 m
Frequency	3.5 GHz
Bandwidth	100 MHz

v) User Terminal (UT) Parameters:

Characterizing the research area determines the UT parameters. The authors chose Jakarta as the dense urban area for this research. Table V shows the UT characteristics needed in dense urban areas [4].

TABLE V: THE PARAMETERS FOR UT IN JAKARTA

Parameters	Value
Transmitter power	49 dBm
Receiver sensitivity	-142.3 dBm
Antenna's gain	2 dBi
Antenna's height	1.5 m
Frequency	3.5 GHz
Bandwidth	100 MHz

4) Network planning simulation

Forsk Atoll, a network radio tool, can simulate coverage prediction. Coverage planning must consider transmitter coverage power, receiver sensitivity, gain antennas, and other factors. This coverage study depends on regional categorical conditions (dense urban, urban, suburban, and rural) and propagation models. The Synchronization Signal Reference Signal Received Power (SS-RSRP) and Synchronization Signal Signal-to-Interference Noise Ratio (SS-SINR) will be analyzed.

5) Economic planning approach

After completing capacity and coverage planning, this research continues with economic planning. The economic planning method identifies a 5G NR network's CAPEX, OPEX, business feasibility, and sensitivity.

i) Capital Expenditure (CAPEX):

CAPEX is the money a company invests in development. Examples are line cards, optical transmission equipment; routers; switches; and servers. CAPEX also includes the network installation and the construction phase. CAPEX cannot be used on items that are less than a year old [7].

ii) Operational Expenditure (OPEX):

OPEX is primarily the cost of the process of operating, maintaining, and repairing networking equipment that requires a large amount of the budget. OPEX is reflected in the profit and loss statement of a company. OPEX is instantly consumed and fully deductible in the year it has incurred. OPEX is taken from revenue to determine profit or loss. OPEX includes the technical, commercial, and administrative costs [7].

iii) Net Present Value (NPV):

TABLE VI: SUMMARY OF THE NPV CATEGORIZATION

NPV Categorization	Project Results	Final Decision
Positive	Acceptable since it provides a return greater than the required rate of return	Proceed with the project
Zero	Acceptable since it provides a return equal to the required rate of return	Proceed with the project
Negative	Not Acceptable since it provides a return less than the required rate of return	Stop the project

NPV estimates a project's profitability based on its initial investment. It evaluates a project's worth. Should the company start the project? NPV determines the profitability of a project's additional funding. Executives use NPV to make capital budgeting decisions. NPV replaces cash inflow with outflow for decision-making. This research's NPV formula is shown in equation (9). Table VI shows the summary of the NPV categorization.

$$NPV = \frac{\sum_{t=1}^{n} R_t}{(1+r)^n}. \quad (9)$$

where,

R_t = the projected periodic net cash flow,
r = the required rate of return per period,
n = the duration of the project.

iv) Internal Rate of Return (IRR):

The IRR is the discount rate that results in zero NPV when applied to cash flows. This discount rate is the projected return. If IRR reaches a target level, the project is approved. If the IRR falls short of the target, the project is rejected. IRR can be estimated using project cash flows. Table VII summarizes the IRR classification. While the equation for IRR is presented in equation (10), as in

$$IRR = r_a + \frac{NPV_a}{NPV_a - NPV_b} \cdot (r_b - r_a). \quad (10)$$

where,

r_a = the lower rate of discount,
r_b = the lower rate of discount,
NPV_a = the NPV at r_a,
NPV_b = the NPV at r_b.

v) Payback Period (PBP):

The PBP technique is based on the premise that the project needs to create sufficient cash flows to pay the investment costs for a period of time. Therefore, projects with a greater or lower PBP can be accepted or rejected based on whether they meet a predetermined number of years. Table VIII presents the summary of the PBP categorization.

TABLE VII: SUMMARY OF THE IRR CATEGORIZATION

IRR Categorization	Project Results	Final Decision
Positive	Acceptable	Proceed with the project
Zero	Acceptable/Not Acceptable	Proceed/Stop with the project
Negative	Not Acceptable	Stop the project

TABLE VIII: SUMMARY OF THE PBP CATEGORIZATION

PBP Categorization	Project Results	Final Decision
PBP year < Maximum PBP year	Acceptable	Proceed with the project
PBP year > Maximum PBP year	Not Acceptable	Stop the project

vi) Profitability Index (PI):

The PI is an indicator that depicts the relationship between a proposed project's costs and benefits. It is calculated as the ratio of the future cash flows to the project's initial investment. A higher PI indicates that a project is better to be chosen. Table IX shows the summary of the PI categorization.

vii) Business Sensitivity:

Business sensitivity identifies which parameters significantly affect project feasibility over the expected parameter range. This research uses a spider diagram to depict baseline, optimistic, and pessimistic. The baseline scenario follows research assumptions. While optimistic and pessimistic scenarios raise and lower business sensitivity [2].

TABLE IX: SUMMARY OF THE PI CATEGORIZATION

PI Categorization	Project Results	Final Decision
PI >1	Acceptable	Proceed with the project
PI =1	Acceptable/Not Acceptable	Proceed/Stop with the project
PI <1	Not Acceptable	Stop the project

IV. RESULTS AND ANALYSIS

A. *Techno-economic Analysis*

In this research, several parameters for the techno-economic analysis simulations are computed. We started with the technical analyses comprised of capacity analysis, coverage analysis, and network simulation using Forsk Atoll software. Then we proceed with economic analyses comprised of CAPEX, OPEX, business feasibility such as the NPV, IRR, PBP, and PI, and finally, the sensitivity analysis. These are summarized in the following Table X.

TABLE X: PARAMETERS FOR TECHNO-ECONOMIC ANALYSIS

Aspect	Planning	Parameters
Technical	1. Capacity	5G user forecasting, population density and traffic projection, and throughput forecasting
	2. Coverage	MAPL, Path loss, and coverage area
Economic	1. Cost structures	CAPEX and OPEX
	2. Feasibility	NPV, IRR, PBP, and PI
	3. Sensitivity	CAPEX, number of users, number of gNodeB, marketing cost, and operation and maintenance cost

B. *Capacity Analysis*

As part of a dense urban scenario's capacity analysis, the forecasting of users, traffic demands, throughput, and final gNodeB requirement are all considered. Also, the categorization of frequency ranges of the 5G network is required to be determined. Table XI shows the 3GPP spectrum frequency channel for the 5G frequency range.

TABLE XI: 3GPP SPECTRUM FREQUENCY CHANNEL WIDTHS FOR FREQUENCY RANGE OF 5G NETWORK

Categorization of Frequency Range	Frequency Range (MHz)	Supported Channel Bandwidth (MHz)
FR1	410 – 7125	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100
FR2	24250 – 52600	50, 100, 200, 400

1) *5G user forecasting*

The capital of Indonesia, Jakarta, is the country's most populous city and is the country's largest metropolitan area. However, Jakarta is not just Indonesia's capital but also the country's economic and government center. Every year, Jakarta sees considerable growth in the number of people moving to the city from outside Jakarta. Jakarta had 4.3 million migrants in 2018 [11]. These migrants were spread over six Jakarta neighborhoods. Forecasting 5G users in each location requires calculating the initial 5G market user. By using equation (1), the prediction of market users is presented in Table XII and Fig. 9, respectively.

TABLE XII: MARKET USER'S FORECAST IN JAKARTA CITY

Municipals	Surface Area (km^2)	Number of Users in 2019	Annual Growth Rate (%)	Number of Users in 2021
North Jakarta	146.66	1,812,915	1.22	1,841,376
East Jakarta	188.03	2,937,859	1.09	2,978,622
South Jakarta	141.27	2,264,699	1.18	2,298,983
West Jakarta	129.54	2,589,933	1.6	2,644,754
Central Jakarta	48.13	928,109	0.34	934,074
Thousand Islands	8.7	24,295	1.79	24,734
Total	662.33	10,557,810	7.22	10,722,543

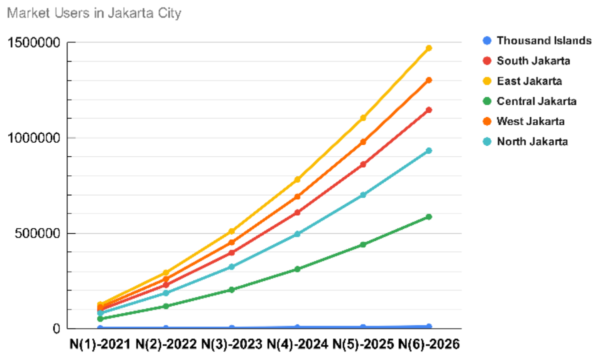

Fig. 9. The forecast of market users from the year 2021 - 2026.

2) *Population density and traffic projection*

The population density in the region where the 5G telecommunications network is deployed requires market potential data in the final deployment year. In this analysis, Telkomsel's market share of 45% is used. The 5G network's traffic projection depends on population growth and market share. The research's population density calculations are displayed in Table XIII.

TABLE XIII: POPULATION DENSITY IN JAKARTA

City/Municipals	Surface Area (km^2)	Number of Population in 2026	Population Density
North Jakarta	146.66	3,487,577	2,996.28
East Jakarta	188.03	5,498,263	3,684.42
South Jakarta	141.27	4,284,084	3,821.01
West Jakarta	129.54	4,870,635	4,737.53
Central Jakarta	48.13	2,190,250	5,733.88
Thousand Islands	8.7	35,477	513.80
Total	662.33	10,557,810	21,487

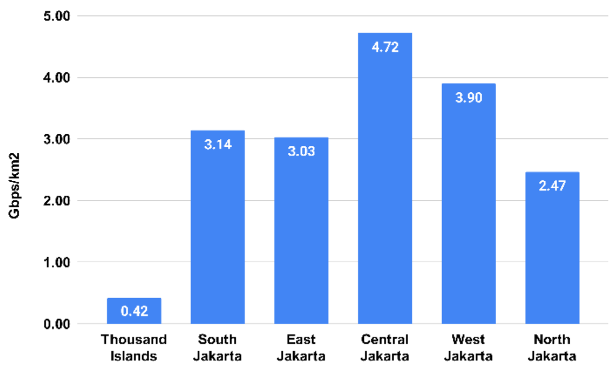

Fig. 10. 5G NR traffic demand forecast in Jakarta city 2026.

At the end of the forecasted year, customer analysis determines population density. This research considers Jakarta's 2026 population. This study calculates 5G traffic demand using the equation (2). Fig. 10 shows Jakarta's traffic data needs. Central Jakarta has the highest traffic demand at 4.72 Gbps/km^2, while the Thousand Islands has the lowest at 0.42 Gbps/km^2 monthly.

3) Throughput forecasting

According to 3GPP, TS 38.306 (3) is utilized to determine the highest uplink and downlink throughput estimation. Table XIV provides 5G NR uplink and downlink data rates for the 3.5 GHz frequency. Fig. 11 illustrates 5G NR data rates at 3.5 GHz. The highest downlink throughput for the data rate is almost double the uplink because of 5G deployment overhead parameters.

TABLE XIV: THROUGHPUT DATA RATE OF 5G NR PARAMETERS

Parameters	Throughput Data Rate of 5G NR 3.5 GHz	
	Uplink	Downlink
Bandwidth	100 MHz	100 MHz
Throughput data rate	937.52 Mbps	1752.75 Mbps
Spacing of subcarrier	30 kHz	30 kHz
Factor of scaling	0.75	0.75
Carrier of component	1	1
Physical resource block	273	273
Number of layers	4	8
Order of modulation	4	4
Overhead	0.08	0.14
Numerology	1	1

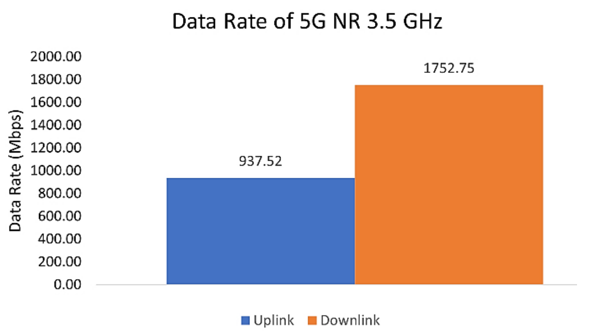

Fig. 11. 5G NR data rates in both uplink and downlink.

C. Coverage Analysis

The Maximum Allowable Path Loss (MAPL), path loss propagation, and coverage area are used to determine the coverage analysis for establishing a 5G NR network in a crowded metropolitan area of Jakarta.

1) MAPL analysis

The link budget values for the 5G NR 3.5 GHz frequency spectrum established by the 3GPP 38.901 standard are used to calculate the MAPL. According to Table XV, the link budget for 5G NR can be determined using the equation (4) and the parameters listed.

i) Path Loss Propagation:

Line of Sight (LOS) is used for both uplink and downlink in this study for outdoor-to-outdoor path loss propagation. The parameters used for calculating the path loss propagation model in a dense urban area for 5G NR NSA are provided in Table XVI.

TABLE XV: PARAMETERS FOR 5G NR LINK BUDGET

5G Parameters	Uplink	Downlink
Antenna gain (dBi)	2	2
Penetration loss (dB)	28	28
Foliage loss (dB)	7.5	7.5
Body block loss(dB)	3	3
Cable loss (dBi)	0	0
Physical resource block	273	273
Tx power (dBm)	49	49
10log10 subcarrier quantity	3276	3276
UT noise figure (dB)	3.5	7
Antenna gain of UT (dB)	10	0
Noise power of thermal (dBm)	-153.93	-153.93
Interference margin (dB)	2	2
Rain/ice margin (dB)	0	0
Slow fading margin (dB)	8	8
SINR of demodulation threshold (dB)	-16.53	-11.54
Path loss (UMa)	99.36	106.42

TABLE XVI: PARAMETERS FOR CALCULATING THE PROPAGATION MODEL OF DENSE URBAN AREA OF 5G

Parameters	Uplink	Downlink
h_{BS} and h_{UT} Distance, d_{3D} (m)	610.02	915.89
Distance of Breakpoint, d'_{BP} (m)	676.67	676.67
Cell Radius, d_{2D} (m)	609.35	915.45
Equipment's Height, h_E (m)	1	1
Height of User Transmitter, h_{UT} (m)	1.5	1.5
h'_{BS} (m)	29	29
h'_{UT} (m)	0.5	0.5
Light speed, c (m/s)	3 10^8	3 10^8

ii) Uplink and Downlink Coverage Area:

Once we obtain the (d2D) parameter value, the following action is to identify the coverage area. Equations (11 - 12) show the calculation results of the coverage area in the design of this research, based on the uplink and downlink as follows,

$$Uplink\ Coverage\ Area = 0.72\ km^2 \quad (11)$$

$$Downlink\ Coverage\ Area = 1.63\ km^2. \quad (12)$$

D. Required gNodeB Based on Capacity Approach

This study calculates the site number needed to deploy 5G NR in all Jakarta's municipalities. Uplink and downlink capacities are determined. East Jakarta has the greatest need for gNodeB, while Thousand Islands has the least. East Jakarta needs 152 uplink and 108 downlink gNodeB. The Thousand Islands needs one uplink and one downlink gNodeB. Fig. 12 shows the capacity uplink and downlink data.

E. Required gNodeB Based on Coverage Approach

After calculating coverage, this study identifies the required sites for 5G NR deployment in the municipality of Jakarta. Thousand Island required the fewest site number compared to East Jakarta, which required the highest site number. East Jakarta needs 261 uplink and 116 downlink gNodeB. Thousand Islands requires 12 uplink gNodeB and 5 downlink gNodeB. Fig. 13 shows uplink and downlink gNodeB for coverage.

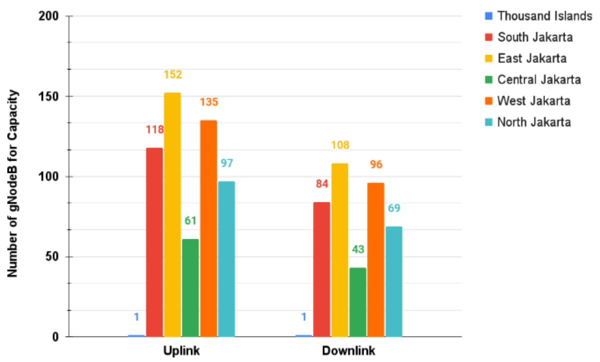

Fig. 12. Capacity uplink and downlink gNodeB.

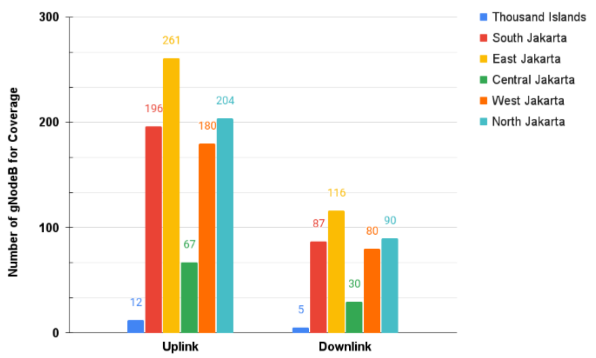

Fig. 13. Coverage uplink and downlink gNodeB.

F. Final Number of gNodeB

According to capacity planning projections for Jakarta's 5G NR NSA network, with 17.7 Gbps/km^2 traffic demand in 2026, uplink needed 563 gNodeB while downlink necessitated 402 gNodeB to cover all 20,366,286 users in Jakarta City. The calculation of coverage planning for the 5G NR NSA network implementation in Jakarta shows that 919 gNodeB for the uplink scenario and 407 gNodeB for the downlink scenario are needed to cover the city's 662.33 km^2 area. When deploying 5G NR NSA 3.5 GHz with 100 MHz bandwidth in Jakarta, the final number of gNodeB must be determined as it is crucial to compare and obtain the most significant site number in both capacity approaches and coverage planning. In this case, 563 gNodeB uplink in capacity and 919 gNodeB uplink in coverage, as shown in Fig. 14. As a result, the maximum number of gNodeB that has been selected is 919 from the coverage planning approach.

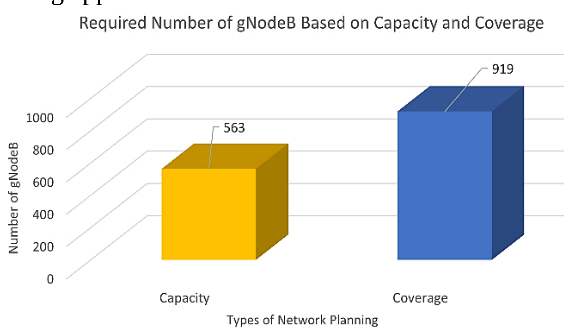

Fig. 14. Number of gNodeB comparison.

G. Network Planning Simulation Analysis

Following the collection of capacity and coverage approach results, a simulation of a 5G NR network rollout was done using the Forsk Atoll network simulator. The required site for the simulation equals the largest gNodeB obtained by comparing and selecting the largest gNodeB from the capacity and coverage calculation results. According to the study's computation, 919 gNodeB are required in Jakarta City.

1) SS-RSRP analysis

In 5G networks, the SS-RSRP permits the comparison of signal levels from individual cells. This parameter determines which cells to pick for handover. Fig. 15 displays Jakarta's SS-RSRP network planning findings. Using the 5G KPIs, the obtained SS-RSRP's mean result of -93.27 dBm, as shown in Fig. 16, is categorized as good.

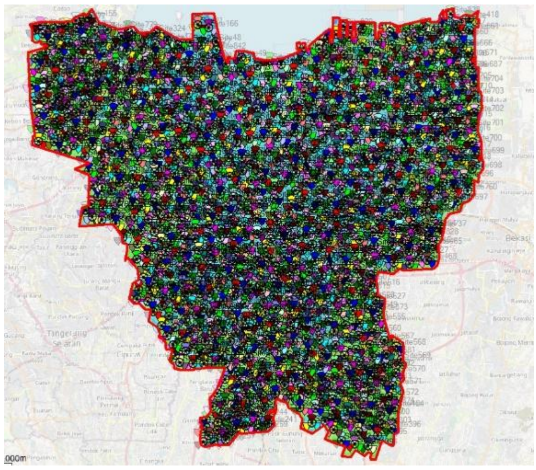

Fig. 15. SS-RSRP network planning plots in Jakarta City.

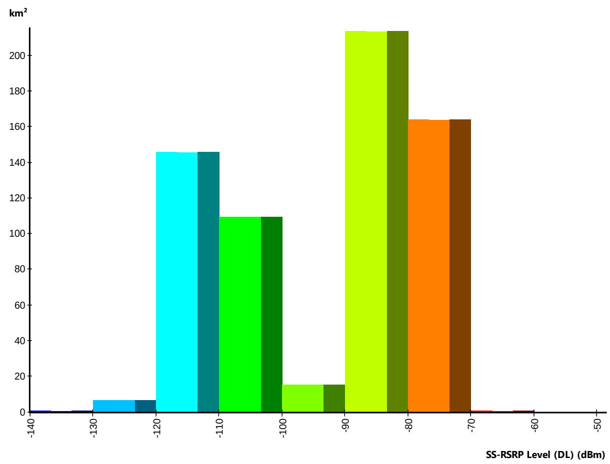

Fig. 16. SS-RSRP network planning results in histogram mode.

2) SS-SINR analysis

SS-SINR compares signal reception to interference noise. In this research, the SS-SINR parameters match the previous 5G KPI range. Fig. 17 shows Jakarta's SS-SINR. Based on 5G KPI's previous range, the obtained SS-SINR mean result of 8.89 dB, as shown in Fig. 18, is considered fair.

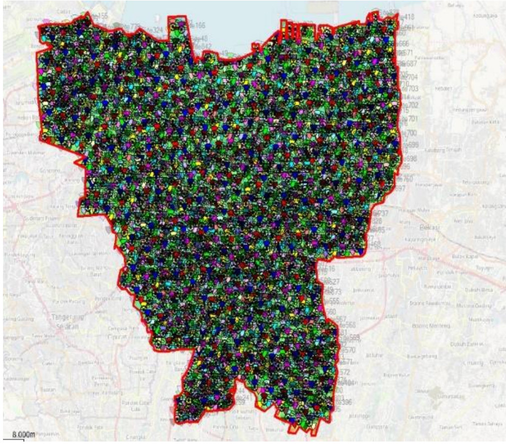

Fig. 17. SS-SINR network planning plots in Jakarta City.

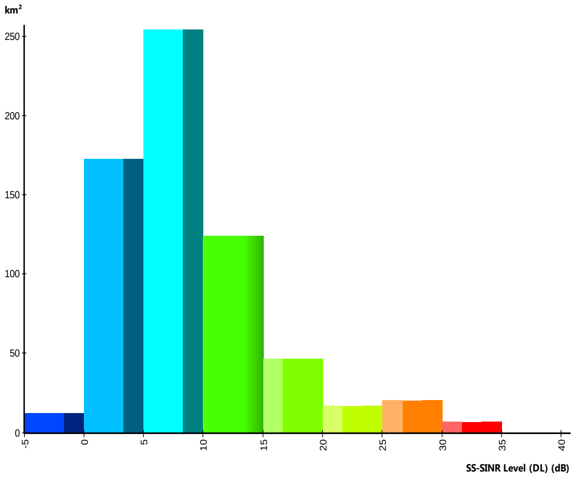

Fig. 18. SS-SINR network planning results in histogram mode.

H. Capital Expenditure (CAPEX) Analysis

This research calculated the CAPEX from 2021 to 2026. This includes the Base Band Units (BBU), RF modules, power supply, and three sectoral antennas are upgraded for 5G NR, with upgrades encompassing 50% of the site. Table XVII illustrates the required CAPEX cost.

I. Operational Expenditure (OPEX) Analysis

The 5G NR OPEX analysis affected the network implementation costs. This research calculated the OPEX required for the deployment to be IDR 1,004,463,403,900. This is because a new 5G infrastructure will be used. Table XVIII forecasts the OPEX cost.

TABLE XVII: CAPEX COST ASSUMPTION FOR 5G NR NETWORK

	List of CAPEX
1.	Base Band Unit (BBU)
2.	Radio Remote Unit (RRU)
3.	Antenna
4.	Combiner
5.	Additional rectifier
6.	Supporting material installation
7.	Installation of equipment
8.	Software and license
	Total IDR 147,184,134,855

TABLE XVIII: OPEX COST ASSUMPTION FOR 5G NR NETWORK

	List of OPEX
1.	Power consumption
2.	Transportation fee
3.	Consumable parts
4.	Operational and maintenance (O&M)
5.	Marketing and advertisement
6.	Spectrum license
7.	Operating rights fee and universal service obligation
8.	Operating rights fee for telecommunication
9.	Depreciation of Equipment
	Total IDR 1,004,463,403,900

i) Power Consumption:

This deployment uses three Radio Remote Unit (RRU) modules and the BBU. The RRU and BBU each consume 20 and 40 watts, respectively, with the annual power bill cost of $87.4 or IDR 1,267,300.

ii) Transport Fee of gNodeB Optic:

The gNodeB needs an optical link to the core. These requirements can be addressed by establishing their optical networks and outsourcing to third parties. The gNodeB requires $662.07 or IDR 9,600,015 per year for its component transportation fee.

J. Net Present Value (NPV) Analysis

NPV is the difference between business cash inflows and outflows. NPV can be determined using revenue, interest rates, and present values from prior outcomes. The modeling period considers the previous year's NPV. If the NPV is greater than zero (positive), 5G NR deployment can be attempted; if it is less than zero (negative), the project cannot be attempted since the business is risky and less beneficial to the company. Table XIX provides 5G NR NSA 3.5 GHz NPV results in Jakarta. NPV values are still negative from 2021 to 2026, but they climb each year until 2026, when it reaches a positive NPV of IDR 477,532,953,385. Based on NPV, 5G NR at 3.5 GHz in Jakarta is possible.

TABLE XIX: THE CUMULATIVE NET CASH FLOW AND YEARLY NET PRESENT VALUE TABLE FOR OPERATOR

Year-N	Cash Inflow (Revenue) (IDR)	Cash Outflow (CAPEX+OPEX) (IDR)	Cumulative Net Cash Flow (IDR)	Net Present Value per Year (IDR)
0	245,399,616,025	1,151,647,538,610	906,247,922,730	788,041,671,895
1	571,812,911,980	1,026,358,890,230	1,497,157,694,310	1,234,854,353,690
2	994,970,063,950	1,071,636,705,505	1,596,824,328,375	1,300,386,783,385
3	1,523,523,407,970	1,128,191,913,325	1,082,893,385,235	1,006,545,098,575
4	2,154,327,120,030	1,195,687,910,545	163,337,587,110	386,948,052,410
5	2,869,289,279,995	1,331,137,666,940	2,162,934,683,980	477,532,953,385

K. IRR Analysis

The IRR is the interest rate at which the NPV of investment expenses (negative cash flows) equals the NPV of investment returns (positive cash flows). An IRR is often used to evaluate an investment or project. IRR increases a project's desirability. Therefore, the one with the greater IRR should be implemented first among similar projects. The IRR is 24.7%. This means that deploying is a good decision.

L. PBP Analysis

PBP is one method for determining an investment's financial viability. This method also estimates how long it will take to recover the initial investment cost using cash inflow. The PBP, or investment return, is 3.87 years, as stated in Table XX. This is derived from the previous three occurrences of raw fraction (-). This means establishing that the investment is fair to implement because the return duration is less than the investment's economic age, which is five years. Fig. 19 depicts the representation of the acquired data.

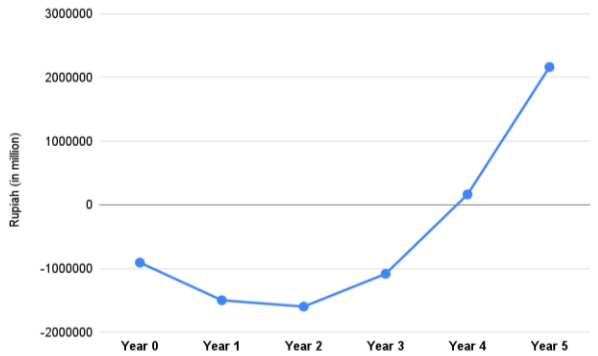

Fig. 19. Cumulative net cash flow that shows the break-even point.

TABLE XX: NET CASH FLOW FROM 5G NR NSA FOR PBP

Year-N	Net Cash Flow (IDR)	Cumulative Net Cash Flow (IDR)	Fraction Raw
0	- 906,247,922,730	-906,247,922,730	-
1	-590,909,771,725	-1,497,157,694,310	-
2	-99,666,633,920	-1,596,824,328,375	-
3	513,930,943,140	-1,082,893,385,235	-
4	1,246,230,972,345	163,337,587,110	0.87
5	1,999,597,096,870	2,162,934,683,980	0.08

M. PI Analysis

The PI calculates the future cash flow-to-investment ratio. The PI helps evaluate investment projects and calculate a value per investment unit. In this research calculation for forecasting PI analysis, Cash Inflow is IDR 4,909,597,703,210, and Cash Outflow is IDR 3,454,186,884,210, providing 1.42 as the PI result. This signifies that the project adds value, and the operator firm may continue with it. Table XXI and Fig. 20 show all the PI results.

TABLE XXI: CASH INFLOW AND CASH OUTFLOW TO GET PI

Year-N	Cash Inflow (Revenue) (IDR)	Cash Outflow (CAPEX+OPEX) (IDR)	PI
0	-	-	-
1	4,909,597,703,210	3,454,186,884,210	1.42
2	5,074,224,446,691	2,809,592,233,138	1.81
3	4,840,388,049,695	2,136,394,370,162	2.27
4	4,042,922,849,149	1,447,261,060,789	2.79
5	2,495,034,156,522	756,254,072,271	3.30

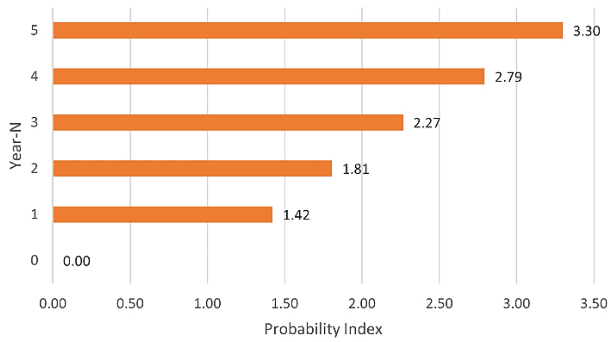

Fig. 20. PI per year for 5G NR NSA.

N. Business Sensitivity Analysis

This research's sensitivity analysis identifies factors that affect project feasibility over the expected parameter range. This study validates each parameter against a specified scenario for deploying 5G NR NSA at 3.5 GHz and 100 MHz bandwidth in Jakarta. The sensitivity research examines these parameters: 1) CAPEX; 2) Users; 3) gNodeB; 4) Marketing Costs, and 5) Operational and Maintenance Costs. These are generated using three business scenarios: 1) Baseline values with no change; 2) Optimistic values with a 10% increase over baseline; and 3) Pessimistic values with a 10% decrease over baseline.

i) Spider Diagram Sensitivity Analysis:

During economic research and feasibility, there is sometimes uncertainty about the input parameters of an economic model. A spider diagram displays the economic impact of changing project attributes. The Spider diagram demonstrates the sensitivity analysis output ranges. Businesses can discover which model inputs affect project economics by analyzing these effects. Fig. 21 shows the spider diagram of this research.

ii) Threshold Scenarios Analysis:

The threshold scenario analysis is used to determine the proportion of the baseline scenario that must be maintained for a business to stay viable. The results of changing the parameters are as follows:

- CAPEX:

CAPEX affects business little. Three sensitivity scenarios have modest effects on NPV, IRR, PBP, and PI. CAPEX's percentage of the threshold value is estimated as 373.11%, as shown in Table XXII. Therefore, changes in the CAPEX sensitivity analysis can be ignored and will not adversely affect the business.

TABLE XXII: CAPEX SENSITIVITY ANALYSIS

Annual Cost	Threshold Value 373.11%	Pessimistic -10%	Baseline 0%	Optimistic 10%
NPV	0	IDR 490,331,573,700	IDR 477,532,953,385	IDR 464,734,332,925
IRR	15.0%	25.0%	24.7%	24.4%
PBP	4.19	3.86	3.87	3.88
PI	1	1.42	1.42	1.42

- The Number of Users:

According to the business sensitivity analysis spider diagram depicted in Fig. 21, the number of users has a comparable influence on the operating and maintenance costs of the firm, but in the opposite direction. It was also an influential parameter while searching for user thresholds for company feasibility. Table XXIII shows that in a 10% pessimistic scenario, NPV, IRR, PBP, and PI are -IDR 33,940,565,280, 14.3%, 4.28, and 1.25, respectively. While in the optimistic scenario, NPV, IRR, PBP, and PI are IDR 989,006,471,905, 34.6%, 3.47, and 1.59, respectively.

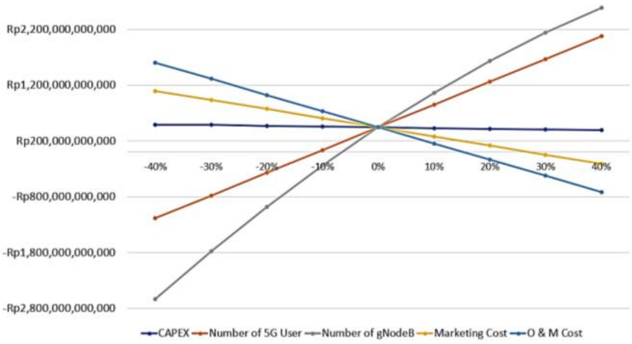

Fig. 21. Spider diagram to illustrate the sensitivity analysis.

TABLE XXIII: NUMBER OF USER SENSITIVITY ANALYSIS

Annual Cost	Threshold Value -9.34%	Pessimistic -10%	Baseline 0%	Optimistic 10%
NPV	0	IDR 33,940,565,280	IDR 477,532,953,385	IDR 989,006,471,905
IRR	15.0%	14.3%	24.7%	34.6%
PBP	4.25	4.28	3.87	3.47
PI	1.26	1.25	1.42	1.59

- The Number of gNodeB:

The number of gNodeB is the most critical 5G NR NSA 3.5 GHz deployment characteristic. In the baseline scenario, the PBP is met in three years and ten months with an NPV of IDR 477,532,953,385. The optimistic scenario is 10% more confident than the baseline scenario and has a negative NPV of -IDR 462,438,814,145. PBP is attainable after four years and seven months. Under the pessimistic scenario, NPV is IDR 1,330,885,992,760, 10% less than the baseline scenario, and PBP is three years and one month. In this business scenario, the quantity of gNodeB and the money spent producing them are related.

Table XXIV shows the gNodeB threshold necessary to obtain NPV at zero and IRR at 15%.

TABLE XXIV: NUMBER OF GNODEB SENSITIVITY ANALYSIS

Annual Cost	Threshold Value -5.20%	Pessimistic -10%	Baseline 0%	Optimistic 10%
NPV	0	IDR 1,330,885,992,760	IDR 477,532,953,385	IDR 462,438,814,145
IRR	15.0%	46.5%	24.7%	6.7%
PBP	4.25	3.12	3.87	4.62
PI	1.26	1.83	1.42	1.13

- Marketing Cost:

Table XXV shows the sensitivity analysis of the marketing costs of the 5G NR NSA 3.5 GHz deployment in Jakarta, which are presented in three scenarios. However, marketing cost does not impact the business as much as the number of gNodeB sensitivity analyses. Therefore, the business is still feasible with an IRR of 15%, PBP of 4.25, and PI of 1.23.

TABLE XXV: MARKETING COST SENSITIVITY ANALYSIS

Annual Cost	Threshold Value 77.44%	Pessimistic -10%	Baseline 0%	Optimistic 10%
NPV	0	IDR 539,201,022,880	IDR 477,532,953,385	IDR 415,864,883,745
IRR	15.0%	25.9%	24.7%	23.5%
PBP	4.25	3.81	3.87	3.92
PI	1.23	1.45	1.42	1.39

- Operation and Maintenance Cost:

TABLE XXVI: OPERATION AND MAINTENANCE COST SENSITIVITY ANALYSIS

Annual Cost	Threshold Value 11.03%	Pessimistic -10%	Baseline 0%	Optimistic 10%
NPV	0	IDR 910,626,594,305	IDR 477,532,953,385	IDR 44,439,312,465
IRR	15.0%	34.8%	24.7%	15.8%
PBP	4.25	3.45	3.87	4.21
PI	1.26	1.61	1.42	1.27

Operational and maintenance costs affect business sensitivity analysis the second most, after the number of gNodeB. The PBP can be met in three years and ten months with an NPV of IDR 477,532,953,385. The 10% more optimistic scenario has an NPV of IDR 44,439,312,465 and a PBP of four years and two months. The pessimistic scenario NPV is IDR 910,626,594,305, 10% less than baseline, and PBP is three years and five months. Operational and maintenance costs are inversely proportional to NPV in this business scenario. Table XXVI shows that 11.03% of the threshold percentage is needed to produce an NPV close to zero and a high IRR of 15%.

V. Conclusion

From the calculation results and planning of the technical aspects of deploying 5G NR NSA 3.5 GHz technology in Jakarta City, it is necessary to cover Jakarta city with 919 gNodeB to implement 5G NR NSA with 3.5 GHz frequency and a bandwidth of 100 MHz in Jakarta City. The simulations for network planning revealed that the mean SS-RSRP value is -93.27 dB and is categorized as good through the 5G KPI range. In addition, the obtained SS-SINR mean value is 8.89 dB and is classified as fair to the 5G NR 3.5 GHz users in Jakarta City. From the calculation and planning of the economic aspects of deploying a 5G network in Jakarta, it can be concluded that the overall total cost for both CAPEX and OPEX is IDR 1,151,647,538,610, with IDR 147,184,134,855 for CAPEX and IDR 1,004,463,403,900 for OPEX to build a 5G network in Jakarta City. The analysis of NPV provided possible results in deploying the 5G network in Jakarta City, resulting in IDR 477,532,953,385 in the final year of 2026. Analysis of the IRR on the deployment of the 5G network in Jakarta City is 24.7%, and this result is feasible for the business. Analysis of the PBP resulted in 3.87 years, equivalent to three years and ten months. This means that the deployment is possible. Analysis of the PI resulted in 1.42. This means that the project creates value, and the operator may decide to continue deploying 5G NR 3.5 GHz in Jakarta City. Throughout this research, an insight into parameters that greatly affect this techno-economic planning is obtained. From the sensitivity analysis result, the most significant impact parameters can be sorted from the highest impact to the lowest impact: Number of gNodeB > Number of users > Operation & maintenance costs > Marketing cost > CAPEX. For future research, exploring 5G with different deployment models and with multiple frequencies and bandwidths scenarios is recommended.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad Imam Nashiruddin was responsible for the overall research idea and implementation. Muhammad Adam Nugraha was given the job of calculating the capacity and coverage. Putri Rahmawati simulated the capacity and coverage results with Forsk Atoll software. Ahmad Tri Hanuranto provided suggestions regarding the economic aspect.

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