Techno-Economic Analysis of the Narrowband Internet of Things (NB-IoT) Network Planning for Smart Metering Services in Urban Area (Study Case: Padang City)

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***Abstract*— Currently, energy monitoring activities in Indonesia are still carried out manually for gas, electricity, and water. However, there is a weakness in manual monitoring, the data cannot be processed in real time. This research was applied in the City of Padang as one of the urban areas in Indonesia. The planning is using Narrowband Internet of Thing (NB-IoT). NB-IoT is a network technology with low frequency bands and low costs. Advanced Metering Infrastructure (AMI) is an application that has a potential to use the NB-IoT network. The development of the NB-IoT network on AMI's services will be carried out with coverage and capacity calculations. After the calculations and simulations NB-IoT carried out, the next step is calculation and analysis of techno-economics. This calculation can be used as a benchmark to test the feasibility of whether NB-IoT on smart metering is suitable or not. Through techno-economics, it can be seen how the impact of implementing NB-IoT on AMI's services, whether it will bring profit or losses in the future.**

***Keywords*— NB-IoT, smart metering, network planning, internet of things, low power wide area network, techno-economics**

I. INTRODUCTION (*HEADING 1*)

Advanced Metering Infrastructure (AMI) is a technology used for energy measurement and has features to view load currents, detect electronic equipment and record customer bills in real time by calculating usage time [1]. These features can be used as a reference point for more save energy consumption. Currently, Indonesia is a country with two fairly large energy uses, namely for crude oil of 1.6 million barrels per day, while for production it is only 800,000 barrels per day. The amount of usage is much greater than the amount of production. Several studies explain that, maximizing energy use can be achieved by using a direct feedback system and energy usage data information that is displayed in real time [1]. With the aim of maximizing energy consumption savings, Advanced Metering Infrastructure (AMI) is the right technology to do so.

AMI is an application that uses IoT with small information delivery over long distances. Therefore, LowPower Wide-Area (LPWA) is the perfect combination for AMI because LPWA has a wide coverage area with lower price and better power consumption [2]. The LPWA technology that will be used in this research is the Narrow Band Internet of Things (NB-IoT). The advantages of using NB-IoT are low power usage, low device costs and deep penetration. In this study, two methods will be used, namely the stand-alone and in-band methods. The stand-alone method uses resources in the form of operator spectrum fragments using a GSM frequency of 1 channel or more dedicated to a bandwidth of 200KHz. While the in band method uses existing LTE resources [3].

At this time, IoT is a technology that is experiencing very rapid development and has great opportunities in the digital industry world and it is estimated that the IoT market opportunities will continue to increase. It is estimated that the current size of the IoT market in Indonesia can generate up to Rp 444.2 billion, of which platforms and applications are the largest contributors with a market percentage of 78% [4].

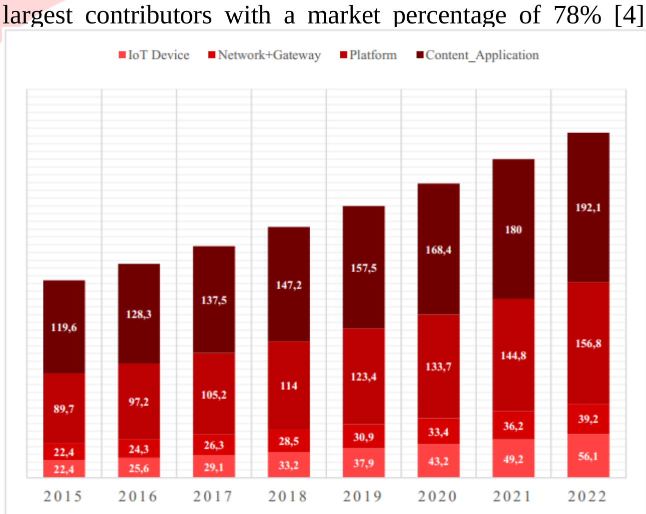

Fig. 1 Indonesian IoT Market Value Chart [4]

After designing the NB-IoT on the AMI, then a techno-economic analysis is carried out on the design. Techno-economic analysis is an analytical method by combining the analysis of technical aspects of the implementation of a technology with its economic value. The parts to be analyzed are Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index, and Payback Period, then look at the economic value of the design. This is useful for determining whether the design is economically feasible to implement. Typically, techno-economy consists of market height, service and cost and performance parameter estimates of the technology required by the customer and can provide good service to the customer [5].

II. NB-IOT TECHNOLOGY

A. NB-IoT Overview

Narrowband-Internet of Things (NB-IoT) has an operating system that is almost the same as LTE and has the same standardization, namely the Third Generation Partnership Project (3GPP) [6]. But there are some features that indicate significant differences with LTE, especially in the areas of power consumption, data rate requirements, and coverage [3].

NB-IoT technology has three operating modes that can be used, namely standalone mode, In-Band mode, and Guardband mode.

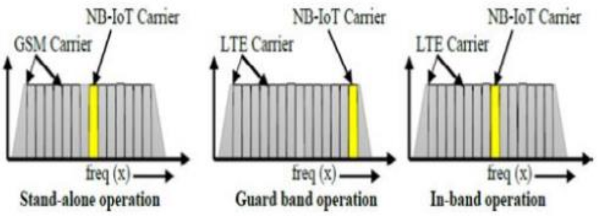

Fig. 2 NB-IoT Operation Mode

In this study, a stand-alone operating mode will be used on the smart meter in the Padang city area. Stand-alone is used due to lower site requirements compared to in-band mode [7]. As for the guard-band operating mode, it still cannot be used in Indonesia because the requirement to use the guard-band operating mode is that 10 MHz of LTE bandwidth is required. Meanwhile, currently Indonesia only has LTE bandwidth of 5 MHz which is held by Telkomsel, Indosat, and XL Axiata respectively [8]. By not allowing the guard-band operating mode to be used, this study uses a stand-alone operating mode with lower site requirements than the in-band operating mode.

Fig. 3. show the architecture of NB-IoT. The NB-IoT device will communicate with the eNodeB after which the NBIoT is connected to the evolved packet core (EPC). Then the eNodeB will send a signal to the EPC. Furthermore, after receiving a signal from eNodeB, the 13 EPCs will forward it to the IoT platform and the IoT platform will forward it to the third party IoT server.

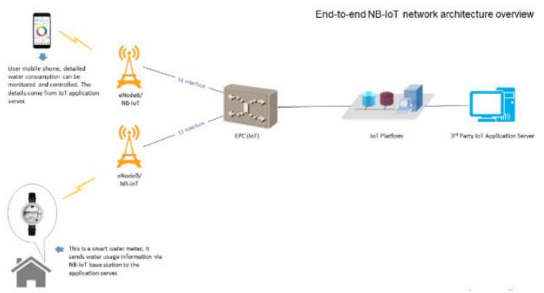

Fig. 3 NB-IoT Architecture [9]

B. *Advanced Metering Infrastructure (AMI)*

Advanced Metering Infrastructure (AMI) is an energy measuring device with advanced technology. Data acquisition is obtained from end users' devices by measuring the use of energy consumption and then providing this information to the utilities involved or operators for monitoring energy consumption.

With a smart meter, energy data such as gas, electricity and water can be measured and energy consumption information recorded in real-time. Smart meter communication is a two-way communication between the meter and the central system. In addition, smart meters have the ability to disconnect loads or reconnect certain loads remotely and smart meters can also be used for monitoring and controlling the devices and equipment used. Not only utilities or operators are involved in using smart meters, but customers are also involved because they can play a role in maximizing energy consumption savings due to the real-time display of smart meter usage [10].

III. Research Metodology

A. *The Number of AMI Devices Required for Ten Years*

In this plan, data is needed in the form of the number of devices from each smart meter such as smart meters for water, electricity, and gas which are used as parameters to calculate the number of sites. The number of devices is assumed from the number of customers from each agency. Data on the number of customers from each agency is obtained from the regional Central Statistics Agency (BPS) [11][12][13].

TABLE I PROJECTION NUMBER OF AMI'S METER DEVICES IN TEN YEARS

Electricity			Water			Gas		
Year	N-Year	Total Customer	Year	N-Year	Total Customer	Year	N-Year	Total Customer
2021	1	655,761	2021	1	101,628	2021	1	10,051
2022	2	672,548	2022	2	103,681	2022	2	10,928
2023	3	689,765	2023	3	105,775	2023	3	11,881
2024	4	707,423	2024	4	107,911	2024	4	12,917
2025	5	725,533	2025	5	110,091	2025	5	14,043
2026	6	744,107	2026	6	112,315	2026	6	15,267
2027	7	763,156	2027	7	114,584	2027	7	16,599
2028	8	782,693	2028	8	116,898	2028	8	18,046
2029	9	802,730	2029	9	119,260	2029	9	19,620
2030	10	823,271	2030	10	121,670	2030	10	21,331
Total		966,272						

B. *Coverage Planning Analysis*

Coverage planning is a cellular network planning method to ensure that the network can provide signal requirements for the entire planning area. There are several aspects that need to be taken into account in carrying out coverage planning, the first is to calculate the Link Budget and the second is to calculate the Maximum Allowable Path Loss (MAPL). This calculation is useful for getting gain loss and maximum coverage distance per gateway [14].

1). Link Budget Calculation

Link Budget is a method of calculating all parameters in signal transmission such as gain and loss from the sender to the receiver through the transmission medium. The link budget is calculated based on the distance between the sender and the receiver, various obstructions are also calculated in the link budget calculation such as trees or buildings. Antenna specifications are also a reference when calculating the link budget [15][16].

$$Prx = Ptx + Gtx + Grx - Losses \quad (1)$$

Where,
Prx = Receiver Power (dBm)
Ptx = Transmitter Power (dBm)
Gtx = Transmit Antenna Gain (dBi)
Grx = Receiver Antenna Gain (dBi)

2) Okumura – Hatta Model

Okumura-Hatta is a pathloss calculation that uses Okumura's calculations and Hatta's propagation model which is based on measurements in urban areas or areas. The validation range of the Okumura-Hatta model is a carrier frequency of 150MHz to 1500MHz with a base station transmitting antenna height of 30 m to 200 m, and the height of the mobile antenna in the range of 1 m to 10 m [17].

$$MAPLu = 69.55 + 26.16\, Log_{10}(f) - 13.82\, Log_{10}(h_b) - a(h_m) + [44.9 - 6.55\, Log_{10}(h_b)]Log_{10}(d)$$

Where,
h_b = height of eNodeB (m)
h_m= height of the AMI devices antenna
d = distance
$a(h_m)$ = AMI's device antenna correction factor

C. *Capacity Planning Analysis*

Capacity planning is a network planning by taking into account the capacity requirements of devices and users who will use the network. Capacity planning is widely used in areas whose feasibility, effectiveness and profitability can be assessed over a long period of time. Based on 3GPP TR 45,820, in calculating gateway capacity, NB-IoT can use the London Model as the basis for household density, number of devices, and number of subscribers [18].

IV. Result and Analysis

A. *Capacity Planning Result*

Based on the calculation of london models, it is determined that the number of devices used is only 40 for each household. Table II shows the number of devices per cell site sector. and at least the capacity of the service can support 52547 devices.

Table II NB-IoT Cell Capacity [18]

Case	Household Density per sq km	Inter-site Distance (ISD)	Number of Device within a Household	Number of Devices within a Cell Site Sector
Urban	1.517	1732 m	40	52.547

The total projected AMI devices of electricity, water, and gas distribution services in the Surabaya area was 966,272 devices. The number of gateway needs based on capacity planning is highly dependent on the number of end-devices, household density per square, inter-side distance, number of devices within a household, and number of devices within a cell site. From calculations using the London models, the results obtained for the gateway requirements are as many as 7 gateways.

B. *Coverage Planning Result*

There are several parameters that affect the coverage planning process such as antenna type, link budget, and frequency. Not only that, Intersite Distance (ISD) also has an influence on NBIoT coverage planning. The okumura-hatta propagation model is the model used in this plan. The size of the cell can be known by using the ISD in a hexagonal pattern. The following is an illustration of ISD [19].

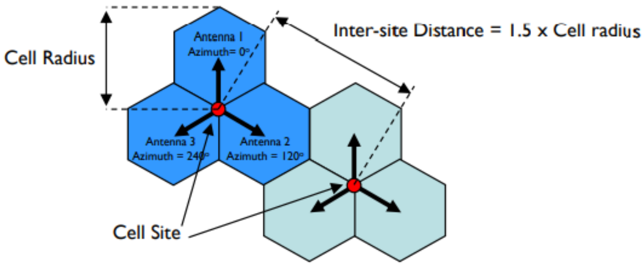

Fig. 4 ISD Illustration

TABEL III NB-IOT COVERAGE PLANNING CALCULATIION

Coverage Calculation	
Frequency	945 MHz
Bandwidth	200 kHz
Transmitter Height	30 m
Receiver Heght	1.5 m
Transmitter Power	43 dBm
Transmitter Gain	18 dB
Correction Factor (a(hm))	0.017788
Receiver Noise	-159 dB
Interference Margin	6 dB
Noise Figure	8 dB
SINR	4.3 dB
EIRP	65 dBm
Sensitivity	-146.7 dB
Cell Radius R	14.24 km
Inter-Side Distance	21.36 km
Cell Site Sector Radius (r)	7.12 km
Cell Area	257.02 km
MAPL	179.7

C. *The Number of Gateway from Coverage and Capacity Calculation*

Based on the calculation of capacity and coverage that has been carried out, it is found that there are differences in gateway requirements between the two calculations. To perform the simulation, the calculation with the largest number of gateways is taken to ensure that the coverage area can reach the targeted area. So in this simulation, 7 gateways will be used to get a large coverage area.

D. *Coverage by Signal Level*

Based on Fig. 5. NB-IoT planning in Padang City using 7 gateways can produce an average signal level of -59.07 dBm with the highest signal level being at -70 dBm over a distance range of 53.6 2 or 16.3%. The lowest signal is at -105 dBm which covers an area of 4.4% of the total area.

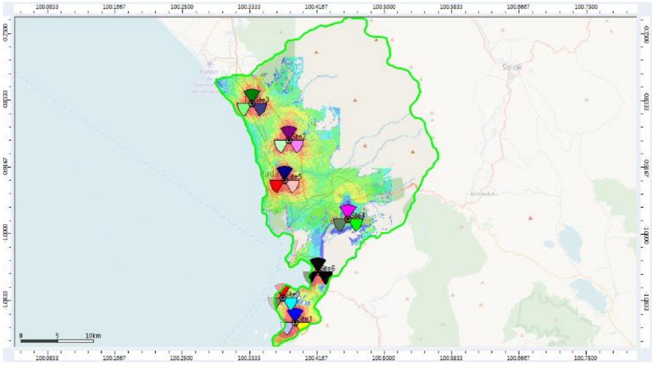

Fig. 5 Simulation Result Coverage by Signal Level in Padang Area

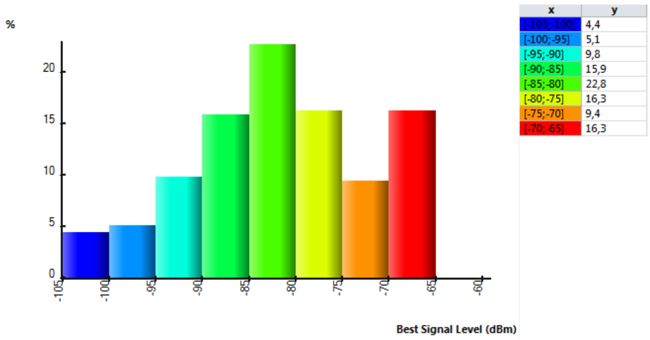

Fig. 6 Histogram Result Coverage by Signal Level in padang Area

E. *Coverage by Throughput*

It can be seen in Fig. 6, each of which is a simulation result based on throughput and histogram from the throughput simulation results using 7 gateways, so the simulation results in an average throughput of 295.45 kbps.

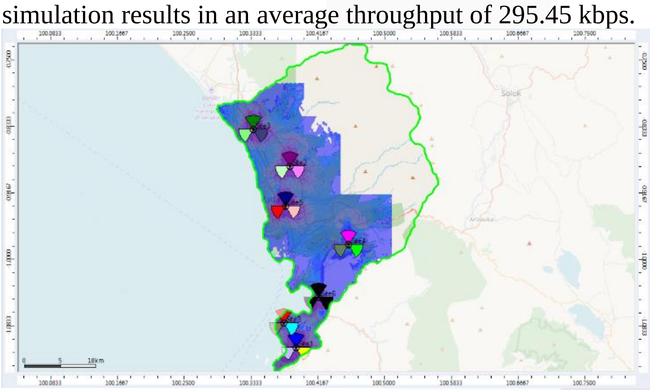

Fig. 7 Simulation Result Coverage by Throughput

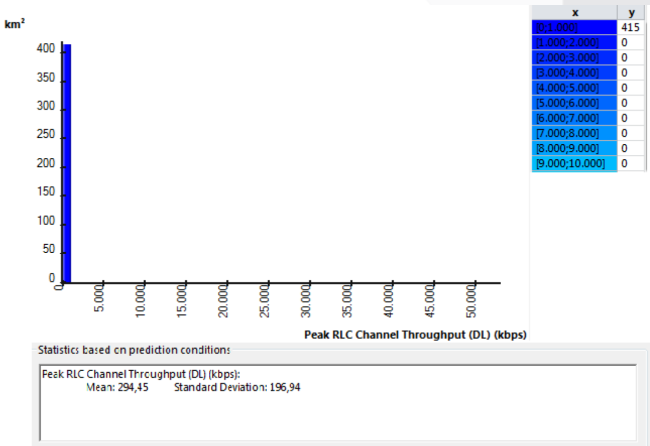

Fig. 8 Covergae by Throughput in Padang Area

F. *Coverage by Signal to Noise Ratio (SNR)*

Furthermore, Fig. 7 is a simulation results based on the Signal to Noise Ratio (SNR) using 7 gateways to produce an average SNR of 12.52 dB with the highest SNR being at 29 dB covering an area of 0.92 % or 3.81 2 and for Figure 4.6 Simulation Results based on SNR in Padang City Figure 4.7 Histogram results based on SNR in Padang 37 The lowest SNR is at -1 dB with an area coverage of 0.8% or 3.33 km^2.

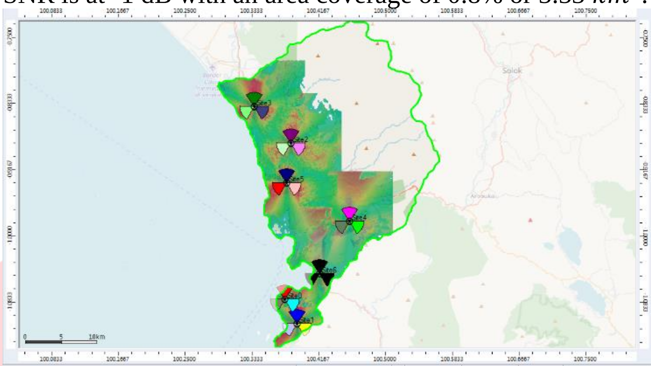

Fig. 9 Simulation Result Coverage by SNR

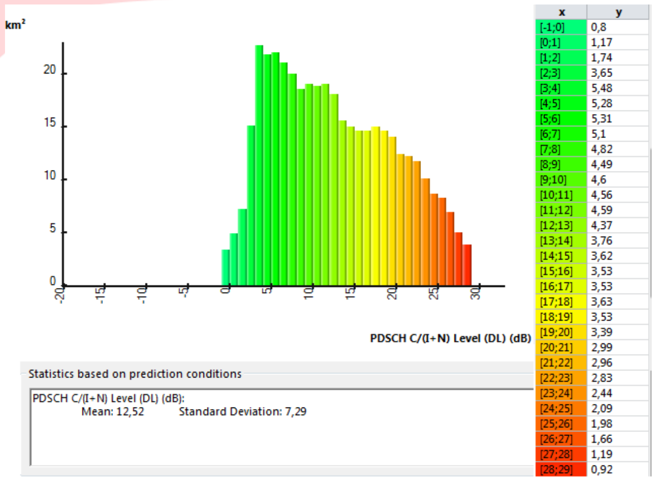

Fig. 10 Histogram Result Coverage by Signal to Noise Ratio

G. *Capital Expenditure (CAPEX)*

Capital Expenditure (CAPEX) is a parameter that shows the costs that will be used in the budget with the aim of buying and repairing everything that is categorized as an agency asset. Then the CAPEX value is shown in table IV.

TABLE IV CAPEX RESULTS PER YEAR NB-IOT TECHNOLOGY

Year	n-Year	Capital Expenditure (CAPEX)
2020	0	$32.819,46
2021	1	$217.889,00
2022	2	$329.641,00
2023	3	$494.971,50
2024	4	$734.081,00
2025	5	$1.068.796,50
2026	6	$1.519.467.50
2027	7	$2.080.837,00
2028	8	$2.712.346,00

2029	9	$3.382.099,00
2030	10	$3.685.492,00

H. Operational Expenditure (OPEX)

represents investment costs related to and used for the daily operational needs of the agency. Then the OAPEX value is shown in table V.

TABLE V OPEX RESULT PER YEAR NB-IOT TECHNOLOGY

Year	n-Year	Operational Expenditure (OPEX)
2020	0	$22.794,57
2021	1	$47.843,13
2022	2	$73.925,40
2023	3	$112.958,37
2024	4	$170.515,90
2025	5	$287.364,99
2026	6	$370.388.86
2027	7	$527.119,19
2028	8	$726.241,29
2029	9	$967.982,39
2030	10	$1.378.531,25

I. Net Present Value (NPV)

Net Present Value (NPV) is a method for measuring investment opportunities and showing the difference in the value of inflows and outflows in the provider's business. Feasibility opportunities can be seen if the NPV value> 0 (Positive), if the NPV <0 (Negative) indicates that a project is not feasible. and in this study, the total NPV for 10 years was $3,964,863.87.

it can be seen that the NPV of NB-IoT until 2030 has a positive result of $ 1,409,582.97. With the data obtained, it can be said that the NB-IoT planning for AMI services in Padang City for the next 10 years is feasible to implement. It is said to be feasible because investment and operational costs can be returned marked with an NPV value> 0 (Positive). It can be seen that in year 4 it has shown a positive NPV valuePV

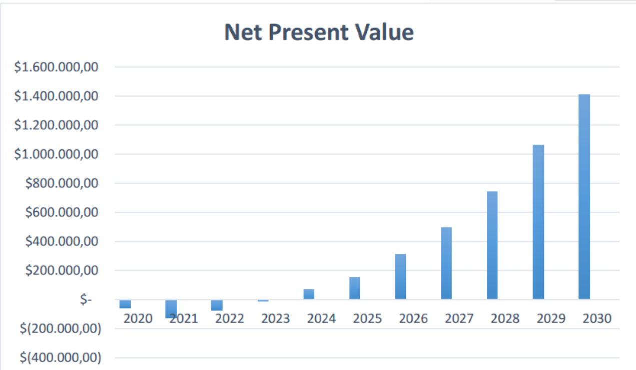

Fig. 11 Net Present Value for Ten Years

J. Internal Rate of Return (IRR)

The NB-IoT network design project for AMI services in Padang City resulted in an IRR of 66.054457%. IRR with a number of 66.054457% can make the NPV value to zero. With an IRR of 66.054457% which is greater than 11.40%, this project can be said to be feasible to implement.

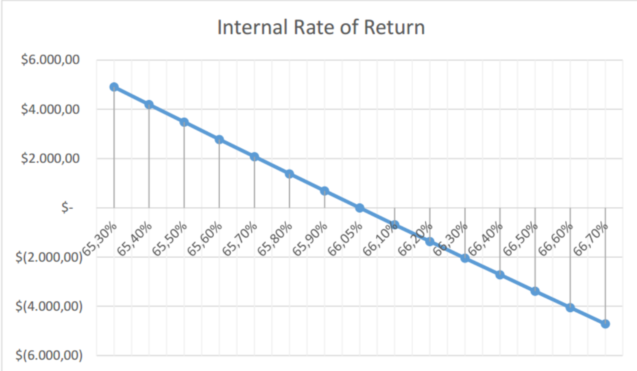

Fig. 12 Internal Rate of Return

K. Payback Period

Payback Period (PP) is how long it takes for a company to return its investment value. PP indicates when a project reaches its Break-Even Point (BEP). From Fig. 10 it can be seen that in the 3rd year the unpaid NB-IoT investment was $16,030,37 and then got a net cash flow of $120,114.88 in the 4th year.

Year	n-Year	Net Cash Flow (NCF)	Cumulative NCF
2020	0	-$55.614,03	-$55.614,03
2021	1	-$86.415,71	-$142.029,74
2022	2	$49.333,74	-$92.696,00
2023	3	$76.665,63	-$16.030,37
2024	4	$120.117,88	$104.087,51
2025	5	$155.828,28	$259.915,79
2026	6	$329.006,05	$588.921,84
2027	7	$462.276,33	$1.051.198,17
2028	8	$710.394,65	$1.761.592,82
2029	9	$1.041.816,68	$2.803.409,50
2030	10	$1.345.582,08	$4.148.991,58

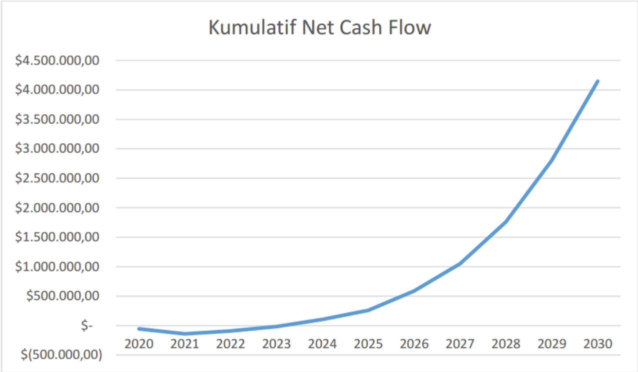

Fig. 13 Payback Period from Cumulative Net Cash Flow

L. *Profitability Index*

Profitability Index (PI) or also known as the investment return ratio is a method to assess the feasibility of a project by comparing the present value and investment value of the project. The PI for the NBIoT planning project with AMI services is 3.3950285, which means this project is economically feasible because the PI value is greater than the determination of the PI feasibility level, which is 1.

V. Conclusion

There are at least four conclusions in this study. first, for planning an NB-IoT-based IoT network using two approaches, namely coverage and capacity, each of which produces a different number of sites using a stand-alone method with 945 MHz frequency and 200 kHz bandwidth which refers to 3GPP R13 standard TR.45,820 . second, Determination of the number of sites is determined by selecting the largest number of sites among the approaches in terms of coverage and capacity. The selection of the most sites is intended so that AMI services in Padang City can cover more areas so that planning can run better. The placement of the site is carried out based on areas that have a large population because most of the city of Padang is mountainous and hilly which can block signal transmission from the site so that the placement of the site is limited to areas that have a large population.

Third, The results of the NB-IoT simulation in Padang City using Forsk Atoll 3.2 get the lowest signal level of -105 dBm, throughput of 295.45 kbps, and the lowest signal to noise ratio of -1 dB, which means from the simulation results it can be concluded that NB-IoT network planning for Padang City has reach the standard.

And the last, The feasibility is not only assessed from a technical point of view, but also from an economic point of view. Where each parameter gets decent results such as NPV of $3,964,863.87, IRR of 66,054457%, Payback Period at the end of the 4th year, and Profitability Index of 3.3950285. The results of each of these parameters have stated that the planning of the NB-IoT network for AMI services in Padang City is economically feasible.

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