LPWA-based IoT Technology Selection for Smart Metering Deployment in Urban and Sub Urban Areas: A State Electricity Company Perspective

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ABSTRACT

The need for LPWA-based Internet of Things (IoT) technology for deploying smart metering services is rapidly growing for its ability to manage energy usage in real-time and increase efficiency. However, the problem faced by electric utility companies is how to choose the most appropriate technology. This study uses a techno-economic approach to compare the two most widely used technological alternatives, namely establishing LoRaWAN as a non-licensed LPWA technology or leasing NB-IoT as a licensed LPWA technology owned by a telecommunications operator. Case studies conducted in the urban area of Bandung and sub-urban city of Tasikmalaya as an example of a typical town in Indonesia. The results showed that LoRaWAN and NB-IoT are both technically and business feasible to be implemented with their respective advantages. LoRaWAN is superior in battery lifetime, business model, speed of implementation, and total costs, whereas NB-IoT is superior in range, capacity, quality of service, security, and ecosystem support. Using PLN's perspective as a national electricity company in Indonesia, LoRaWAN has a Net Present Value of 23% higher than NB-IoT in the 10^{th} year.

1. Introduction

Currently, Low Power Wide Area (LPWA) based Internet of Things technologies are gaining interest. They are characterized by their support for long-range coverage and devices with low power and low throughput requirements. LPWA networks could grow to 3.5 billion connections in 2025, with several sectors contributing to the growth (Mackenzie & Rebbeck, 2016), including utilities such as smart electricity metering.

Utilities in many countries use smart electricity meters to monitor the usage of energy in near real-time, to improve efficiency, and to balance supply and demand. The smart electricity meter requires two ways monitoring on the flow of electricity and information to enable automated and distributed energy delivery (Nair, 2017). The capability of the LPWA technology to provide a two-way communication enables the interaction between the utility operations and the monitoring through control devices.

Perusahaan Listrik Negara (PLN) as a state-owned utility company in Indonesia has an opportunity to address this challenge and use LPWA technology as the most feasible solution for smart electricity metering implementation. Beyond the operational efficiency, the innovation enables PLN to be faster in responding the need of their customers. A research by Nashiruddin (2019) shows that faster market responsiveness will bring the company competitive advantage.

There are some LPWA based Internet of Things technologies available to support the implementation. However, NB-IoT and LoRa WAN are chosen because they are expected to account for around 85.5% of all LPWA connections on a worldwide basis by 2023 (Ratliff, 2019), as presented in Figure 1.

Some scholars have conducted several studies on how to implement Smart Meter using LoRa and NB-IoT. For instance, Wibisono et al (2017) conducted the techno economic analysis of LoRaWAN for Smart Meter in PLN Bali. Bagariang et al (2019) who carried out the planning and the simulation of the LoRaWAN network implementation for smart electricity meter, smart gas meter, and smart water meter in three different geographical types, namely Urban, Sub Urban and Rural areas. Another research has been performed by Purnama & Nashiruddin (2019) to explore the LoRaWAN network deployment for smart electricity, gas,

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water meter and gasoline meter for Surabaya, Gresik and Sidoarjo Cities. Meanwhile, Santoso et al (2019) investigated NB-IoT implementation for electricity smart meter from mobile operator perspectives. Unfortunately, none of the previous works compared the use of LoRaWAN and NB-IoT technology in different geographical types. Therefore, this study aims to provide technology selection analysis for the implementation of LPWA-based smart electricity meter by comparing the use of 3GPP standard technology, namely NB-IOT, and a non-3GPP technology, namely LoRaWAN, from the perspective of *Perusahaan Listrik Negara* (PLN) by considering the importance of technical and economical aspects.

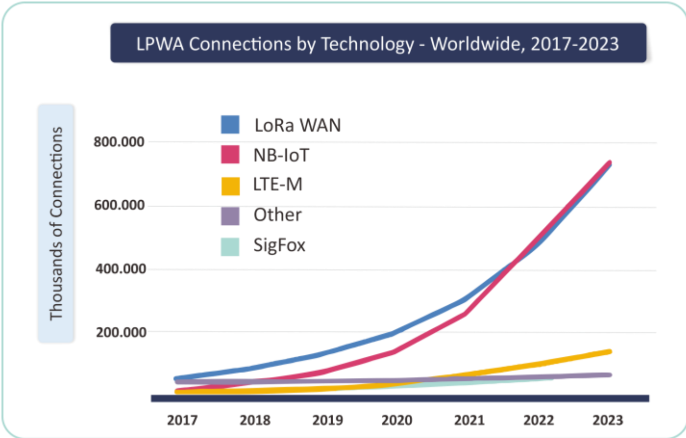


Figure 1. LoRa and NB-IoT technologies are predicted to dominate the market by 2023 (Ratliff, 2019)

2. Literature Review

IoT connectivity technologies have become mature and widespread. IoT covers a wide variety of cases serving diverse requirements because no single communication technology fits all applications. LPWA describes a group of wireless communication technologies designed to support IoT deployments to deliver reliable connectivity over a large area, excellent power efficiency, massive scale, low-cost communication hardware, and low bandwidth (Vodafone, 2017).

2.1. Long Range (LoRa) Wide Area Network (WAN)

LoRa WAN is projected to support a significant portion of billions of Internet of Things (IoT) devices. It is designed to optimize LPWA for battery lifetime, capacity, range, and cost. LoRa in the physical layer is based on chirp spread spectrum, which maintains the low power but significantly increases the communication range. It provides longer distances as well as more robust communications. LoRa WAN defines the communication protocol and system architecture for the network, while the LoRa physical layer enables the long-range communication link (LoRa Alliance, 2015).

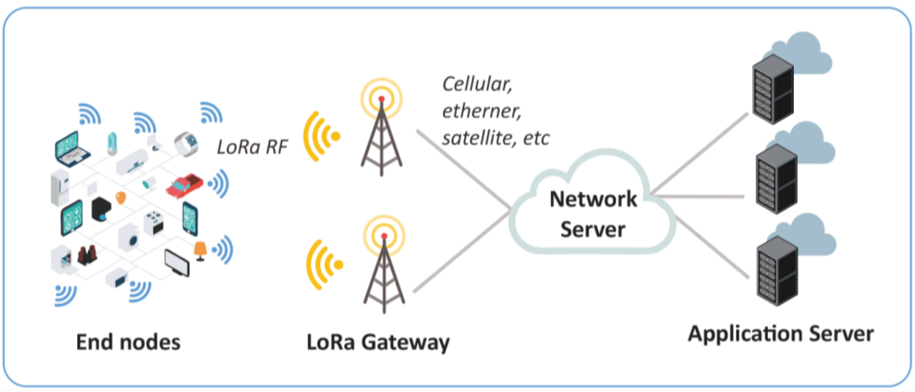


Figure 2. LoRa WAN Architecture (LoRa Alliance, 2015)

In a LoRa WAN network, nodes are not linked with a specific gateway. Instead, the data transmitted by a node is typically received by multiple gateways. Each gateway will forward the received packet from the end-node to the cloud-based network server via backhaul, either through cellular, Ethernet, satellite, or Wi-Fi. The nodes in a LoRa WAN network are asynchronous and active only when they have data to send, either event-driven or scheduled. LoRa WAN works in unlicensed bands require much less capital than licensed bands or software upgrades (LoRa Alliance, 2015).

2.2. Narrowband Internet of Things (NB-IoT)

Narrowband Internet of Things (NB-IoT) is cellular LPWA-based connectivity technology. It is an open global standard that is able to guarantee security, interoperability, scalability, quality of service, and longevity (Vodafone, 2017). It is designed to address low power wide area requirements. Therefore, NB-IoT is suitable for large-scale deployments. NB-IoT also gains support from a wide number of industry participants that can be the best choice for long-term deployments.

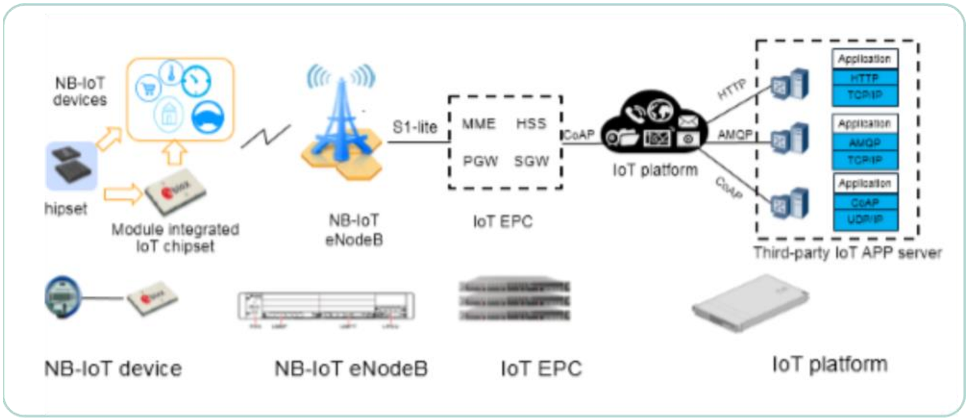


Figure 3. Narrowband-IoT (NB-IoT) Architecture (Huawei, 2018)

The followings are the description of each element of NB-IOT architecture as presented in Figure 3 (Huawei, 2018):

a. NB-IoT Device: IoT devices with corresponding SIM card.
b. NB-IoT eNodeB/Base Station: The base station that has already been deployed by the telecom service provider, and it supports all types of deployment scenarios of NB-IoT.
c. IoT EPC/Core Network: Core network of LTE system that connects base station to cloud platform.
d. IoT Platform: IoT platform process various services, and results are forwarded to the vertical business centre or NB-IoT terminal.

Table 1. Overview of LPWA Technologies: LoRaWAN vs NB-IoT

	LoRa WAN	NB-IoT
Modulation	Chirp Spread Spectrum (CSS)	QPSK
Frequency	Unlicensed ISM Band (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia	Licensed LTE Frequency
Bandwidth	125 kHz, 250 kHz, 500 kHz	180 kHz
Bidirectional	Yes / Half Duplex	Yes / Half Duplex
Max Payload Length	243 bytes	1600 bytes
Interference Immunity	Very High	Low
Authentication and Encryption	Yes (Aes 128b)	Yes (LTE Encryption)
Adaptive Data Rate	Yes	No
Handover	Yes	No
Allow Private Network	Yes	No
Standardization	LoRa Alliance	3GPP

Source: (Mekki et al., 2018)

2.3. Smart Electricity Meter Application

Smart electricity meter is part of a smart grid system that helps to address challenges on surrounding energy consumption and growing environmental concerns. Smart meters allow utility providers to optimize energy distribution while also empowering consumers to make smarter decisions about their energy consumption. The goal is to achieve better management of electrical energy and to provide an efficient balance between supply and consumption (Lloret et al., 2016).

A smart electricity meter is a digital electronic device that collects information of electricity and sends it securely to the utility. It provides information of the real-time consumption for both the utility company as well as for consumers. This data allows us to understand the consumption habits, to improve network efficiency, and to save electricity. By using smart meters, we can manage electricity consumption and monitor any impact on the network in real-time (Lloret et al., 2016). Figure 4 shows an actual model of smart electricity meter.

Figure 4. Smart Electricity Meter (Zheng & Lin, 2013)

3. Research Method

This study analyses 2 (two) relevant potential technologies for smart metering implementation, namely NB-IoT as a licensed and LoRaWAN as a non-licensed LPWA technology. The framework of this study is presented in figure 5.

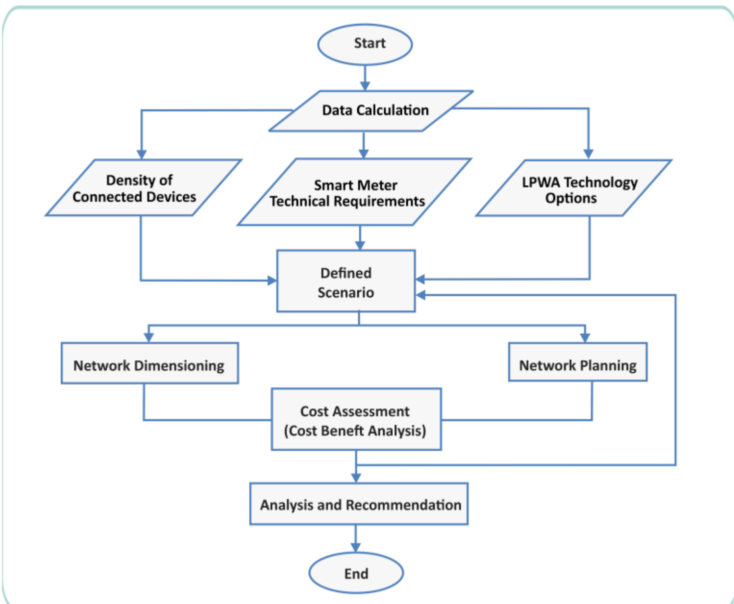


Figure 5. Research Framework

3.1. Data Calculation

3.1.1. Smart Meter Technical Requirements

The smart meter features used in this research are described in Table 2. Overall, there is no necessary bandwidth needed. Proper connectivity technology is required to ensure longevity and full-featured functionality. Table 2 shows the features and technical requirements of smart metering (Nair, 2017).

Table 2. Smart Meter Technical Requirements

Report Types	Smart Meter Features	Typically Occurred	Payload Size	Periodic inter-arrival time	Event Frequency in a day per device	Payload Size in a day per device
1. Periodic Report	Scheduled / Periodic Meter Reading	Weekly, Daily, Hourly, even Minutely basis	20 bytes	Every 4 hours	24/4	120 bytes
2. Exception Report	Outage Restoration and Management (ORM)	Few months or even years	20 bytes	Per event	1	20 bytes
3. Network Command	On-demand Meter Reading, Time of Use Pricing	Weekly, Daily, Hourly, even Minutely basis	20 bytes	1 day, 2 hours, 1 hour, 30 minutes, etc.	1	20 bytes
4. Software Update/ Reconfiguration Model	Software Update	Per 6 Months or Yearly	200 – 2000 bytes	180 Days	1	200–2000 bytes

Source: (Nair, 2017)

3.1.2. The Density of Connected Devices

In this study, the analysis is caried out on two area categories, namely high-density and low-density area. Bandung and Tasikmalaya, two cities in West Java were chosen respectively as the sample for typical urban and sub urban cities in Indonesia. The density ratio for those cities is 3.5 to 1.

As shown in Figure 6, Bandung is categorized as a densely populated area, with a population of about 2,507,888 people and a total area of 167.67 km^2. While the other city, Tasikmalaya, is classified as a low-density area with the population of about 663,517 people and a total area of 171.61 km^2. Future research, however, can be developed on other cities included in PLN's coverage.

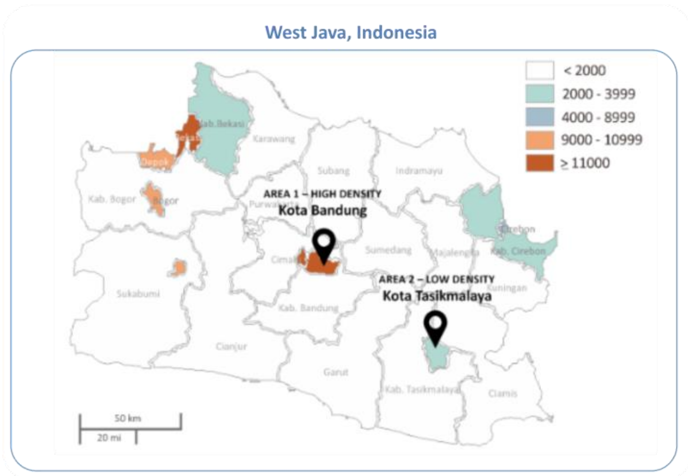


Figure 6. Population Density Map of West Java, Indonesia (Badan Pusat Statistik, 2019)

3.1.3. LPWA Technology Options

LPWA technology options used in the analysis of this study are leasing Narrowband-Internet of Things (NB-IoT) as a licensed LPWA technology owned by a telecommunications operator and establishing Long Range Wide Area Network (LoRaWAN) as a non-licensed LPWA technology.

3.1.4. Defined Scenario

Figure 7 shows four proposed scenarios for the analysis.

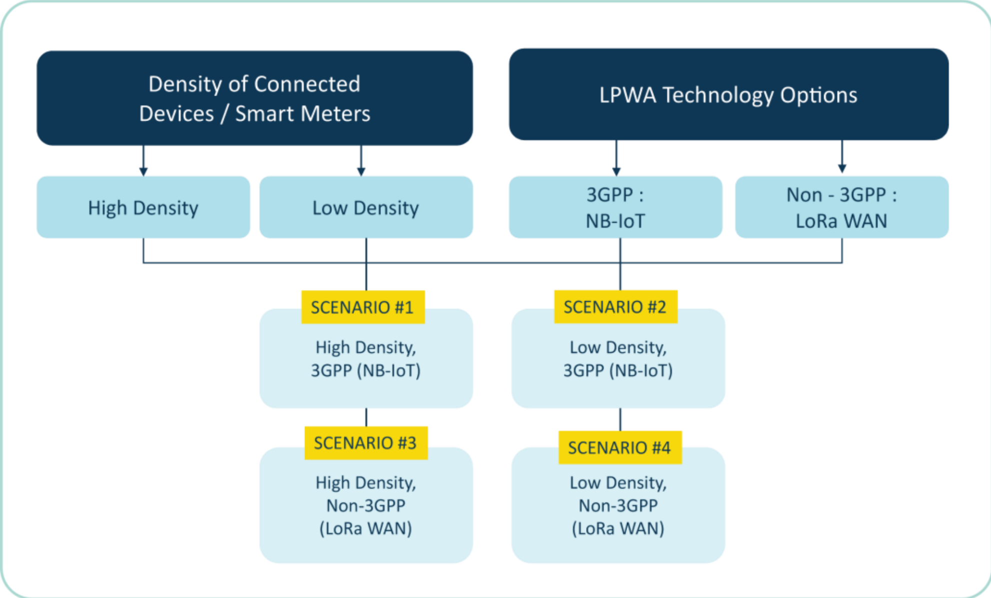


Figure 7. Proposed Scenario

3.1.5. Network Dimensioning

Dimensioning objective is to determine the total required bandwidth to carry the aggregated traffic for the specified quality of service (QoS). By referring to PLN's statistical data in 2018 (PT.PLN, 2018) and the population data from Statistics Indonesia (2019), it can be assumed that the number of the meter is about 26% of the number of population in a defined area.

Table 3. Population and Meters Data for Bandung and Tasikmalaya

Parameters	Bandung (High Density)	Tasikmalaya (Low Density)
Coverage Area	167.67 km^2	171.61 km^2
Population	2,507,888	663,517
Number of Devices	670,000 meter	172,000 meter
Device Density	3,996 meter / km^2	1,002 meter / km^2

Source: (Statistics Indonesia, 2019)

Smart meter subscribers are projected for ten years with annual growth rate refers to average customer growth, that is 6% (PT.PLN, 2018).

1. LoRa WAN

The network capacity can be estimated based on inputs taken from the packet Time on Air (ToA) or transmission time for the various data rate and the data rate distribution. According to Semtech (2013), the duration of a LoRaWAN frame or called Time on Air (ToA) is composed of a preamble and the actual packet payload as presented by equation 1 to equation 4.

$$Time\ on\ Air\ (ToA) = T\_Preamble + T\_Payload \quad (1)$$

$$T\_Preamble = (n\_preamble + 4.25).\ T\_sym \quad (2)$$

$$T\_Payload = payloadSymbNb\ .T\_Sym \quad (3)$$

$$payloadSymbNb = 8 + max\ (ceil\left(\frac{8PL-4SF+28+16-20H}{4\ (SF-2DE)}\right)(CR+4),0\ ) \quad (4)$$

1) n_preamble is 8
2) 4.25 in equation (2) is symbols added by radio
3) T_sym: 2SF / Bandwidth (BW)
4) PL: the number of payload bytes.
5) SF: The spreading factor
6) H: 0 when the header is enabled and H = 1 when no header is present.
7) DE: 1 when the low data rate optimization is enabled, DE = 0 for disabled.
8) CR: the coding rate from 1 to 4 (1 correspond to CR 4/5, 4 correspond to CR 4/8)

Since the main goal in this research is to measure the coverage of the network, the spreading factor (SF) for coverage prediction is set to the highest (SF=12). Based on ToA calculation, a single gateway capacity can be obtained.

2. NB-IoT

The NB-IoT capacity calculation is based on LTE capacity. The NB-IoT and LTE FDD 900 MHz are essentially the same networks because of they share the same hardware equipment. The planning of NB-IoT is the planning of the LTE FDD 900 MHz network. In this research, deployment mode used is in-band LTE deployment in 900 MHz. 1 single carrier NB-IoT is 1 LTE physical resource block (PRB) with 180 kHz bandwidth. NB-IoT capacity can be scaled up by adding more carrier.

Based on 3GPP TR 45.820 Technical Specification Group GSM/EDGE Radio Access Network; Cellular System Support for Ultra-Low Complexity and Low Throughput Internet of Things, details on Annex E resulting the NB-IoT capacity 52.547 devices per cell, or 157.641 devices per site with assumption 3 sectors per site (3GPP, 2015).

3.1.6. Network Planning

The planning objective is to obtain proper site location and parameters that should satisfy coverage requirements by making initial site selection and implementation parameters (antenna type/azimuth/tilt/altitude/ feeder type/length) or gateway parameters and coverage prediction.

a. Link budget calculation

This calculation is to estimate the signal strength loss on the path (path loss) between base station/gateway and the smart meter. We can use the estimation to define the maximum coverage of a site.

b. Coverage Calculation

According to the estimated path loss and the maximum coverage of one site, we can determine the number of sites or gateways required to cover a defined area. Simulation of coverage prediction is generated using Forsk Atoll 3.3.2.

3.2. Cost-Benefit Analysis (CBA)

Cost-Benefit assessment starts with identifying feasible alternatives for smart metering network deployment. As mentioned in the previous sub section, we have four scenarios involving two variables, the area density and technology options. After determining the scenarios, it is continued with the identification of the technical requirements related to smart metering implementation followed by a calculation of cost requirements. The estimate of the investment value consists of capital expenditure (CAPEX), operational expenditure (OPEX), and net present value (NPV).

In CBA, the excess of total benefit over total cost is represented by the net present value (NPV). The NPV is calculated by applying a 'discount rate' to the identified costs and benefits. The NPV formula is presented in equation 5 (Commonwealth of Australia, 2006):

$$NPV = \sum_{0}^{t} \frac{B_t - C_t}{(1+r)^t} \quad \text{……………………………………………..(5)}$$

Bt is the benefit at time t
Ct is the cost at time t,
r is the discount rate

(Bt - Ct) is also known as Cash Flow. Cash inflows have positive values, while cash outflows have negative values. For any given period of *t*, all the cash flows (positive and negative) are calculated together. Table 4 presents an overview of the costs and benefits per stakeholder (CRU, 2017). In general, there are 3 (three) main stakeholders for the smart meter implementation: (1) Telco Service Provider, (2) Utility Company, and (3) Consumers.

Table 4. Costs and Benefits Overview for the Smart Meter Rollout by Stakeholder

Stakeholder	Cost	Benefit
1. Telco Service Provider or Network Provider	The cost associated with the communication network (NB-IoT or LoRa WAN) deployment, include planning, designing, and implementation.	The benefit associated with connectivity usage from vertical industries or client as a network user
2. Utility Company (PLN)	The cost associated with the smart meter implementation program. (1) Capex: material and installation cost and (2) Opex: O&M cost for a technical lifetime, communication cost, and customer service cost	Avoided costs and benefits due to the smart metering rollout are categorized into: First, decreasing operating cost of current business / improving efficiency, and Second, generating additional revenue from new services
3. Consumers	Time costs for learning about the smart meter and other program elements.	Consumption change leads to a reduction in electricity bills, and time savings from avoided the manual meter reads.

Source: (CRU, 2017)

This study limits the analysis only to the perspective of Perusahaan Listrik Negara (PLN) as a utility company that is in charge of smart meter implementation and assumed will be rolled out nationwide soon. Smart meter implementation is projected for ten years period, and the NPV is calculated in each year.

4. Results and Discussions

4.1. Capacity Analysis

LoRa and NB-IoT are the leading LPWA technologies in the IoT industry in recent days. LoRa is an unlicensed technology developed by Semtech with transmission bandwidth of 125 kHz, 250 kHz, or 500 kHz. In this study, the bandwidth of 125 kHz is used. Meanwhile, the transmission bandwidth of NB-IoT is 180 kHz. This bandwidth is called a Physical Resource Block (PRB). The capacity analysis is done to answer the question of how many end devices can be served by a single site.

1. Long Range (LoRa) WAN

Gateway Capacity: The capacity of the LoRa WAN gateway is measured by the number of packets per day. The throughput of a LoRa end device depends on its transmission mode, of which the mode is specified by a combination of bandwidth (BW), spreading factors (SF), and coding rates (CR) (Yousuf et al., 2018). The calculation is done using a fexed 125 kHz bandwidth, various spreading factors from 7 to 12, and different coding rates from 1 to 4. 20 bytes as typical smart meter payload for a periodic, exception, and command report is used for this calculation.

Required Capacity: The capacity requirement is obtained based on traffic characteristics and technical requirements of the smart meter. As defined before, the scenarios are based on the density of smart meters. Therefore, the total required packet per day per area is presented in Table 5 and Table 6. Based on the calculated gateway capacity and capacity requirement, it is possible to calculate the minimum number of LoRa WAN gateway by using equation 6.

Min. Required LoRa WAN Gateway = Required Capacity / Single Gateway Capacity……………………..(6)

Table 5. Total Required Packet per Day for High-Density Area: Kota Bandung

Features	Event Frequency	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of Required Packets
Scheduled Meter Reading	per 4 hours/device	670,000	6	20%	10%	5,226,000
On-Demand Meter Reading	50 per 1000 device (5%)	33,500	1	20%	10%	43,550
Time of Use (ToU) Pricing	100 per 1000 device (10%)	67,000	1	20%	10%	87,100
Firmware Updates	1 per 1000 device per 6 months	670	100	20%	10%	87,100
Outage Restoration and Management (ORM)	1 device per event	670,000	1	20%	10%	871,000
Total Required Packet Per Day						6,314,750

Source: (Tabbane, 2016)

Table 6. Total Required Packet per Day for Low-Density Area: Kota Tasikmalaya

Features	Event Frequency	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of Required Packets
Scheduled Meter Reading	per 4 hours/device	172,000	6	20%	10%	1,341,600
On-Demand Meter Reading	50 per 1000 device (5%)	8,600	1	20%	10%	11,180
Time of Use (ToU) Pricing	100 per 1000 device (10%)	17,200	1	20%	10%	22,360
Firmware Updates	1 device per 6 months	172	100	20%	10%	22,360
Outage Restoration and Management (ORM)	1 device per event	172,000	1	20%	10%	223,600
Total Required Packet Per Day						1,621,100

Source: (Tabbane, 2016)

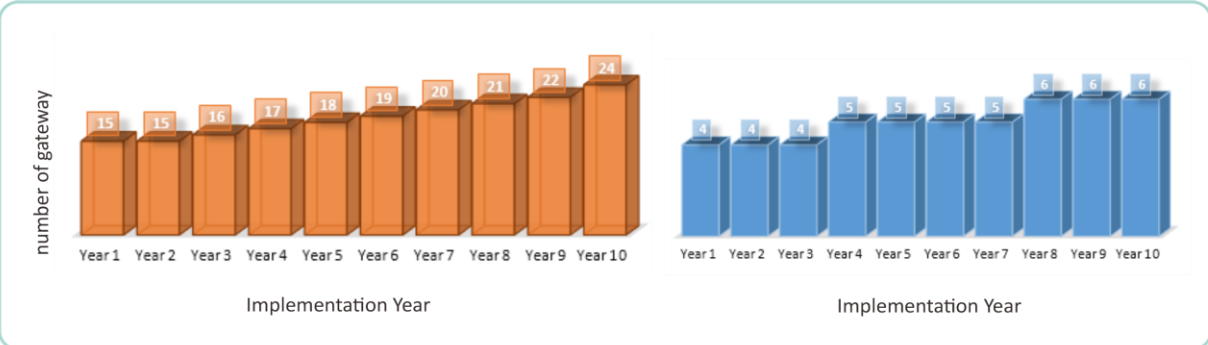
Based on the calculation above, there are margins to anticipate peak load. Burstiness margin is assumed to be the highest percentage of excess load on a network to expect the surge in traffic. Security margin is used to cater for traffic bursts on small time-scales (Tabbane, 2016).

Projected Customer Growth: In this study, to obtain maximum coverage, the spreading factor (SF) is set to the highest (SF=12) and the most robust coding rate (CR) of 4/8 is used. The number of sites is projected for ten years implementation. The expected customer growth is 6% and is started since year 3, while year 1 and 2 are phase of investment. By refering to table 5 and 6, the required capacity can be determined by using equation 1 to 4 and the single gateway capacity can be obtained. Meanwhile, equation 6 is used to obtain the minimum number of the required LoRa WAN gateway. The results are presented in detail on Table 7.

The result can be shown in Figure 8. Where in the first year minimum LoRa WAN gateway needed are 15 for the high-density area and 4 for the low-density area.

Table 7. Minimum Required LoRa WAN Gateway by Year

Implementation Year	Kota Bandung			Kota Tasikmalaya		
	Required Capacity	Single Gateway Capacity	Min. Required LoRa Gateway	Required Capacity	Single Gateway Capacity	Min. Required LoRa Gateway
Year 1 (Investment Phase)	6,314,750	437,176	15	1,621,100	437,176	4
Year 2 (Investment Phase)	6,314,750	437,176	15	1,621,100	437,176	4
Year 3 (Start Grow)	6,693,635	437,176	16	1,718,366	437,176	4
Year 4	7,095,253	437,176	17	1,821,468	437,176	5
Year 5	7,520,968	437,176	18	1,930,756	437,176	5
Year 6	7,972,226	437,176	19	2,046,601	437,176	5
Year 7	8,450,560	437,176	20	2,169,397	437,176	5
Year 8	8,957,594	437,176	21	2,299,561	437,176	6
Year 9	9,495,049	437,176	22	2,437,535	437,176	6
Year 10	10,064,752	437,176	24	2,583,787	437,176	6



(a) Kota Bandung (b) Kota Tasikmalaya

Figure 8. Projected Customer Growth of LoRa WAN Gateways

2. Narrowband IoT (NB-IoT)

Narrowband IoT capacity calculation is based on LTE capacity. The NB-IoT and LTE FDD 900 MHz are necessarily the same networks because they share the same hardware equipment. This research used in-band LTE deployment in 900 MHz as deployment mode. 1 single carrier NB-IoT is a one LTE physical resource block (PRB) with the bandwidth of 180 kHz.

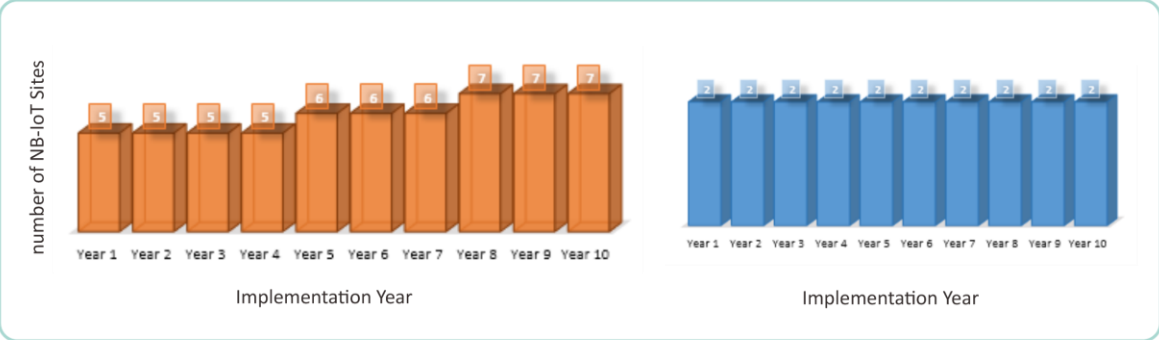
According to 3GPP TR 45.820, the capacity generated by an NB-IoT is based on the area density per square km, Inter-site Distance (ISD), and the number of device in an area (3GPP, 2015). From these three factors, the site capacity of NB-IoT can be obtained. The NB-IoT network capacity can support as many as 52.547 devices per cell or 157.641 devices per site, with an assumption of three sectors per site. The research analysis uses 3GPP TR 45.820 with the London model (3GPP, 2015) as a reference for single NB-IoT site capacity. Meanwhile, the number of user or device is calculated by utilizing the data on the Table 3 with an assumption of 6% of consumer growth starting in the third year. Therefore, the minimum number of NB-IoT sites can be calculated by using equation 7. The results are presented in the Table 8.

Min. Required NB-IoT Sites = Target user or device / Single NB-IoT Site Capacity……………………...……(7)

The result can be shown in Figure 9. Where in the first year minimum NB-IoT sites needed are 5 for the high-density area, and 2 for the low-density area.

Table 8. Minimum Required NB-IoT Sites by Year

Implementation Year	Kota Bandung			Kota Tasikmalaya		
	Target User/ Device	Single Site Capacity	Min. Required NB-IoT Sites	Target User/ Device	Single Site Capacity	Min. Required NB-IoT Sites
Year 1 (Investment Phase)	670,000	157,641	5	172,000	157,641	2
Year 2 (Investment Phase)	670,000	157,641	5	172,000	157,641	2
Year 3 (Start Grow)	710,200	157,641	5	182,320	157,641	2
Year 4	752,812	157,641	5	193,259	157,641	2
Year 5	797,981	157,641	6	204,855	157,641	2
Year 6	845,860	157,641	6	217,146	157,641	2
Year 7	896,611	157,641	6	230,175	157,641	2
Year 8	950,408	157,641	7	243,985	157,641	2
Year 9	1,007,432	157,641	7	258,624	157,641	2
Year 10	1,067,878	157,641	7	274,142	157,641	2



(a) Kota Bandung (b) Kota Tasikmalaya

Figure 9. Projected Customer Growth of NB-IoT Sites

4.2. Coverage Analysis

1. Urban Area (Kota Bandung)

As mentioned previously that Kota Bandung is selected to represent the urban area. To calculate the distance between a base station (or gateway) and a smart meter, this study utilizes Hata channel model for a city as presented in equation 8 (Cooper, 2016).

$$PL = 69.55 + 26.16\log10\, f - 13.82\log10\, hB - CH + [44.9 - 6.55\log10\, hB]\log10\, d \quad \text{......................(8)}$$

hB = Height of gateway antenna above ground (m)
hM = Height of Thing's antenna above ground (m)
f = Transmit frequency (MHz)
CH = Antenna height correction factor
d = Distance from a gateway to a smart meter (km)

2. Suburban Area (Kota Tasikmalaya)

The Hata model for the suburban environment is applicable for the transmissions on areas where human-made structures are there but not as high and densely populated as in the cities. This study chooses Tasikmalaya to represent the suburban area.

$$Lsu = Lu - 2\left(\log10\frac{f}{28}\right)^2 - 5.4 \quad \text{......................(9)}$$

LSU = Path loss in suburban areas. (dB)

LU = Average path loss from the small city version of the model (above). (dB)

f = Frequency of transmission. (MHz).

4.2.1. Long Range (LoRa) WAN

Table 9 presents several parameters that are used to analyse LoRa WAN. Equation 8 and 9 are used to calculate a LoRa WAN gateway coverage for an urban area and a suburban area, respectively. The sites/gateways needed can be calculated using the service distance.

Table 9. Configuration Parameters for LoRa WAN

Parameters	Value	Reference / Remarks
Frequency Band	920 – 923 MHz	Minister of ICT Act No. 1/2019
Min RX Sensitivity	-137 dBm	For DR0, Spreading Factor (SF) = 12 (Highest)
Cable Loss	1 dBm	Based on Assumption
EiRP	16 dBm	LoRaWAN 1.1 Regional Parameters

Source: (LoRa Alliance Technical Committee Regional Parameters Workgroup, 2017)

This study uses Forsk Atoll 3.3.2 as a tool to obtain coverage prediction using the assumed parameters. Figure 10 and Figure 11 shows the coverage prediction for LoRa WAN in the urban and suburban scenarios.

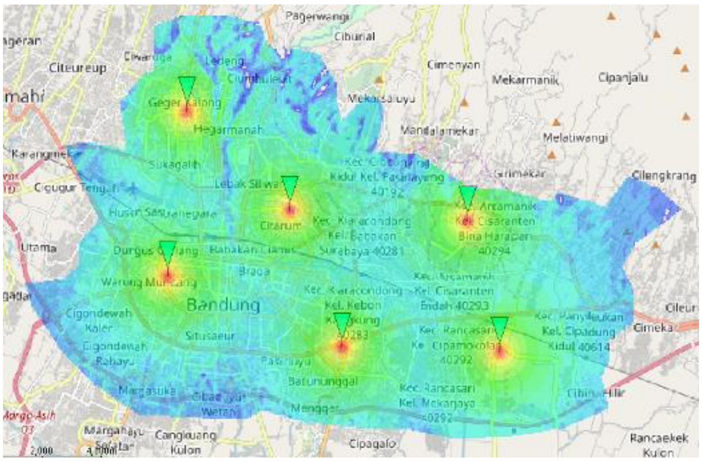


Figure 10. Coverage Prediction for LoRa WAN in Urban Scenario

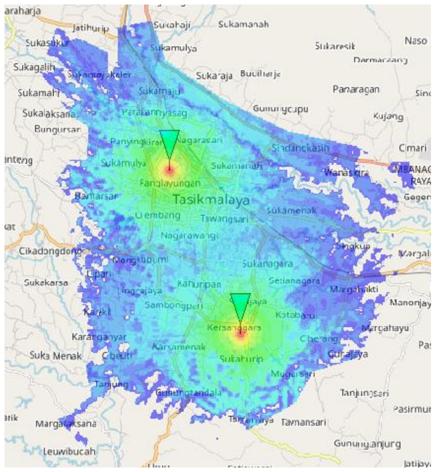


Figure 11. Coverage Prediction for LoRa WAN In Suburban Scenario

4.2.2. Narrowband *IoT* (NB-IoT)

Table 10 displays the parameters to analyse the NB-IoT. Like in LoRa WAN, the coverage of an NB-IoT site can be calculated by using equation 8 and equation 9, respectively. By using the service distance, this study obtains the total number of sites/gateways required to fulfil the predicted demand. Figure 12 and Figure 13 show coverage prediction for NB-IoT in the urban and suburban scenarios.

4.3. Economic Aspects

After evaluating the technical aspects, the economical aspects are reviewed for ten years of implementation of the LoRa WAN and NB-IoT network to reach the entire region of Bandung and Tasikmalaya. This study assumes that the deployment and construction phases of the smart meter up to the completion ofl the initial investment will take five years. This assumption is applied to all scenarios. Operational and technical lifetime is started in year 2 and concluded after year 10. The benefit is calculated starting in year 2. Therefore, no proceeds are considered during the first year of deployment. Table 11 shows a target of smart meter installed by total.

Table 10. Configuration Parameters for NB-IoT

Parameters	Value	Reference / Remarks
Frequency Band	880 - 915 MHz	3GPP Rel 13 Band 8
Min RX Sensitivity	-141 dBm	3GPP T Release 13 397 R 45.820 V2.1.0 (2015-08)
Cable Loss	1 dBm	Based on Assumption
EiRP	23 dBm	3GPP T Release 13 397 R 45.820 V2.1.0 (2015-08)

Source: (3GPP, 2015; Song, 2017)

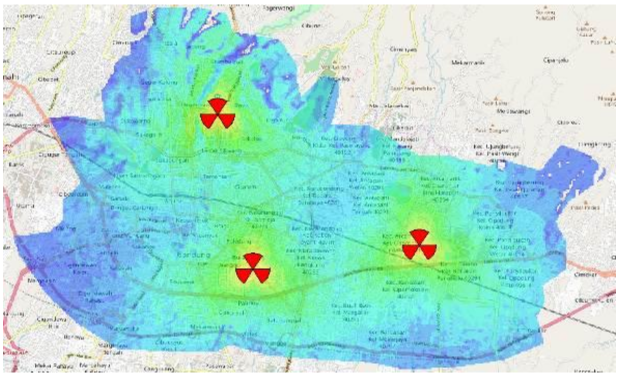


Figure 12. Coverage Prediction for NB-IoT in Urban Scenario

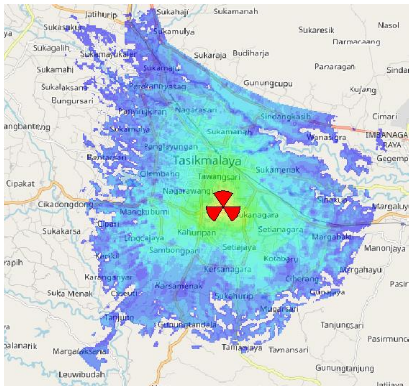


Figure 13. Coverage Prediction for NB-IoTin Suburban Scenario

Table 11. The Target of Smart Meter Installed

Location	The number of meters
Kota Bandung (High Density)	670,000 meters
Kota Tasikmalaya (Low Density)	172,000 meters

It should be noted that the deployment of gateways and Base Stations (BS) are assumed to be done only in the first year of implementation. For LoRa WAN, it will add to investment-related costs since the first year. For NB-IoT, with a leasing scheme, it will be added in year 1 along with recurring or operational costs (see details on cost structure). Firstly, the business model needs to be determined.

4.3.1. Business Model Determination

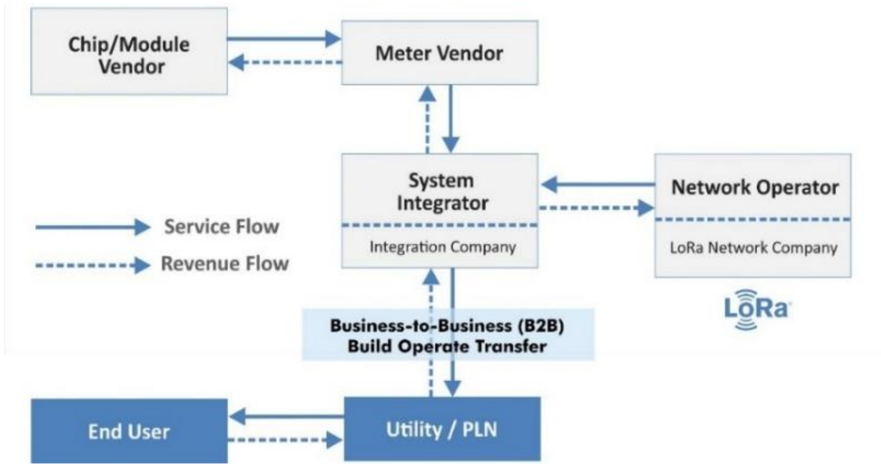
In this research, two different business models were applied. Build Operate Transfer (BOT) model is used for LoRa WAN with several considerations, such as the cost-effectiveness during the initial period of building and operation, reduced operational risk, and the possibility of having control over operational performance (Wibisono et al., 2017). However, the disadvantages of this model are the investment cost and the risk of failure of the implementation are high. The causes are the lack of knowledge related to the implementation process.

For NB-IoT, a feasible business model in Indonesia is the leasing model. Telecommunication operator is the party that has an authority to use NB-IoT over a licensed spectrum. Some of the advantages of this model are lower risk during occuring errors on implementation, possibility of control over operational performance, the availability of service standards and maintenance with a certain service level agreement. However, the disadvantages are loss of managerial control due to the involvement of the third party and the potential of threat on the security of essential company data.

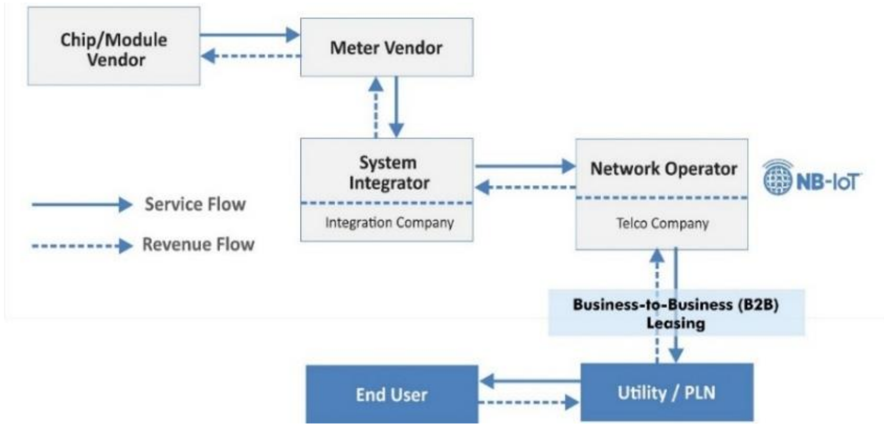
There is a difference between the busineness models of LoRaWAN-based and NB-IoT-based smart metering. In LoRaWAN model, PLN cooperates with an integrator company. In contrast, in NB-IoT model, PLN cooperates with a telecommunication company as the spectrum license holder. In this study, cost assessment is carried out from the perspective of PLN as a utility company in Indonesia.

4.3.2. Cost and Benefit Structure

The total cost of smart meter deployment is the sum of capital expenditure (CAPEX) and operational expenditure (OPEX). The CAPEX consists of material cost and installation cost. The OPEX consists of operation and maintenance costs, data transfer costs, and customer service costs (Pillai K.R., Bhatnagar R., 2016). All the components will be calculated to obtain the total cost of smart metering implementation. The elements of Capex and Opex are presented in Tables 12 and 13.



(a) LoRaWAN



(b) Narrowband IoT (NB-IoT)

Figure 14. Business Model of Smart Metering for LoRaWAN and NB-IoT

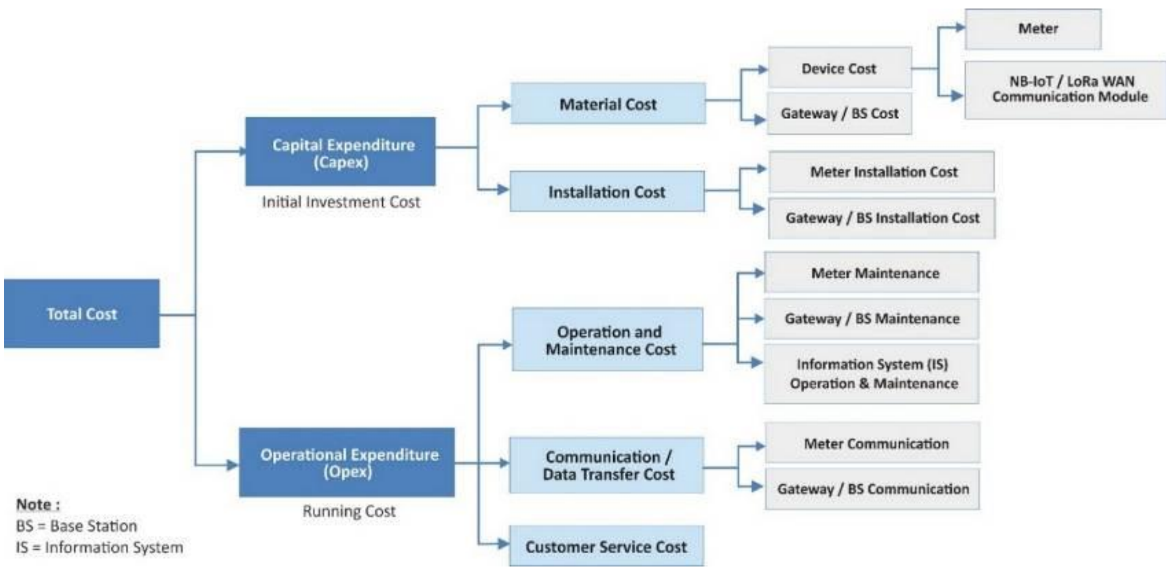


Figure 15. Smart Metering Cost Structure (Actility, 2018; Pillai K.R., Bhatnagar R., 2016)

Table 12. Smart Metering Investment Cost or Capital Expenditure (Capex)

Capital Expenditure (Capex) Elements		Detail Elements (Unit)	Cost per Unit (US$D)	Reference
1.Material Costs	a. Device Cost	1). Meter	7	(Wibisono et al., 2017), (Pillai K.R., Bhatnagar R., 2016)
		2). LoRaWAN Module	10	(Ray, 2018)
		3). NB-IoT Module	12	(Ray, 2018)
	b. Gateway / Base Station Cost	1). LoRaWAN (overlay)	100 – 1.000	(Wibisono et al., 2017), (Pillai K.R., Bhatnagar R., 2016), (Actility, 2018)
		2). NB-IoT (Upgrade to R13 - Leasing)	*Shift to Opex*	
	c. Spectrum Cost	1). LoRaWAN	Free	(Actility, 2018)
		2). NB-IoT (Leasing – cost per device)	*Shift to Opex*	
2.Installation Cost	a. Meter Installation Cost		5	(Pillai K.R., Bhatnagar R., 2016)
	b. Gateway Installation Cost (5% 1.b)		50	(Pillai K.R., Bhatnagar R., 2016), (Kalalas, C., Ning, L., Zhang, R., Wu, Y., Laya, A., Markendahl, J., & Höglund, 2014)

Table 13. Smart Metering Running Cost or Operational Expenditure (Opex)

Operational Expenditure (Opex) Elements	Detail Elements (Unit)	Period	Cost per Unit (USD)	Reference
1. Operation and Maintenance (O&M) Cost	a. Meter Maintenance: Returns and Repair (e.g. Physical Replacement: battery, etc)	Yearly	10% of Capex	(Kalalas, C., Ning, L., Zhang, R., Wu, Y., Laya, A., Markendahl, J., & Höglund, 2014)
	b. BS / Gateway Maintenance (e.g Manual Firmware Update)	Yearly		
	c. IS Maintenance (data storage, processing, and analytics)	Monthly	30 - 100	(Kalalas, C., Ning, L., Zhang, R., Wu, Y., Laya, A., Markendahl, J., & Höglund, 2014)
2. Leasing Cost (for NB-IoT)	a. Spectrum License Fee	5 Years	105.26	(Nugroho & Wibisono, 2018)
	b. Tower Rental & Operational	Yearly	3024.91	
3. Communication / Data Transfer Cost (2 Mbps)		Monthly	15	(Wibisono et al., 2017)
4. Customer Service Cost	a. Support and Troubleshooting	Monthly	10	-

Based on Gibbons (2015), benefit can be obtained in two ways: (1) Decreasing operating costs of current business and/or (2) generating additional revenue. These two strategies help consider whether the solution will be an internal or external focus. While the former strategy involves business operation that is internally focused, the later is externally focused.

4.3.3. Net Present Value (NPV) and Sensitivity Analysis

From the previous calculation, the total cost and total benefit are obtained. Total cost is the sum of investment cost (CAPEX) and running cost (OPEX). Meanwhile, the overall benefit is the sum of decreasing operating costs of current business (internal benefit) and additional revenue of new devices and/or services (external benefit). A further analysis can be conducted to find the net present value (NPV) of the smart meter investment, with 6% discount rate (r), by using equation 5.

In this study, a sensitivity analysis is also presented to determine the parameters that subject to change or have a high level of uncertainty. The range of the change identifies inputs upon which the NPV is most strongly dependant on, indicating which elements are most critical to the overall deployment success (CRU, 2017). Table 14 shows the essential parameters of sensitivity analysis.

Table 14. Parameters for Sensitivity Analysis

Parameters	Assumptions and Baseline	Sensitivity	Impacted	Pessimistic Value	Optimistic Value
1. Projected Customer Growth	Projected Customer Growth is using the nominal baseline: 6 per cent	A variation of 1 per cent (+/-) in customer growth.	Cost, Benefit, NPV	5 per cent	7 per cent
2. Material Costs	Meter and module cost today is higher than tomorrow. baseline: USD 17 - 19	A variation of material costs associated with operating cost	Cost, NPV	USD 17 – 19 (No change from baseline)	USD 7 – 10 (USD 7 for LoRaWAN and USD 10 for NB-IoT)
3. Annual Savings (Internal Benefit)	Annual savings can be in the form of meter reading costs, data entry costs, faster fault meter detection, technical loss reduction, etc. Baseline: 4 per cent	A variation of 2 per cent (+/-) of annual savings	Benefit, NPV	2 per cent	6 per cent
4. Additional Revenue (External Benefit)	Smart Meter device and services revenue (External Benefit) based on reference (SK Telecom, 2016),[] Baseline: USD 0.92	A variation of additional revenue from devices and services	Benefit, NPV	USD 0 (Customer not willing to pay)	USD 1.75 Based on reference (SK Telecom, 2016), with consideration for premium features in the future.
5. Discount Rate	The present value of all costs and benefits has been calculated using the nominal baseline: 6 per cent.	A variation of 1 per cent (+/-) in the discount rate	NPV	5 per cent	7 per cent

Source: (CRU, 2017)

The total value for costs and benefits over the ten-year lifespan of the Cost-Benefit Analysis (CBA) for all scenarios is presented in Figure 16 until Figure 19. The figures are in the form of total non-discounted and the total discounted (NPV). The sensitivity analysis is also considered.

In the pessimistic and baseline scenario, the total cash flow for non-discounted and discounted (NPV) are negative. It means the smart meter implementation is not feasible because the ten years of implementation fails to return the investment spending. After considering several parameters that can be changed into an optimistic scenario, the NPV changes to a positive value for all alternatives start in year 5. The elements that are most critical to the deployment success can be identified as follows:

a. Material and Associated Operating Costs

The meters, communication modules, and associated operating costs represent the most substantial proportion of capital spending on the smart meter deployment. Variations and slight changes in the cost of material and associated operating costs have a tremendous impact on the overall NPV due to scaling across the number of meters/devices.

b. Additional Revenue (External Benefit)

The additional revenue associated with the level of customers' willingness to pay represents the most significant benefit to the smart meter deployment. The benefit is calculated based on a reference of SK Telecom (2016). The average service price per device per month is USD 0.92. Based on a research by Suryanegara et.al (2019), this number is still at an acceptable level.

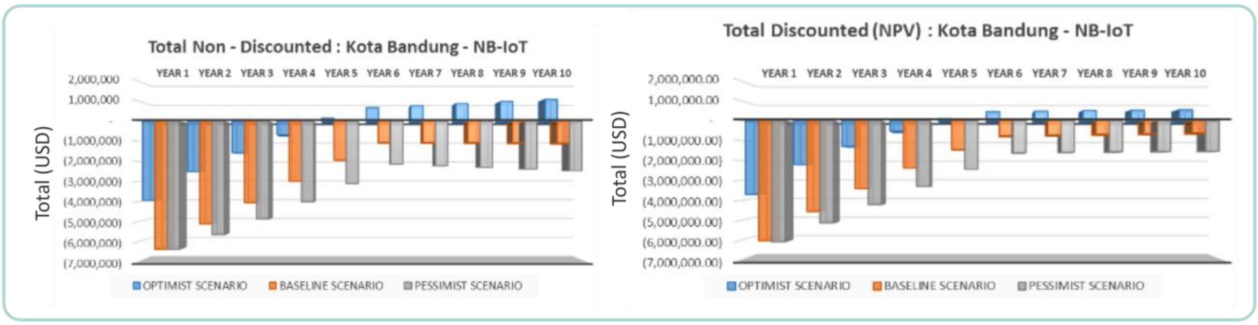


Figure 16. Total Cashflow: Kota Bandung – NB-IoT for Non-Discounted and Discounted (NPV)

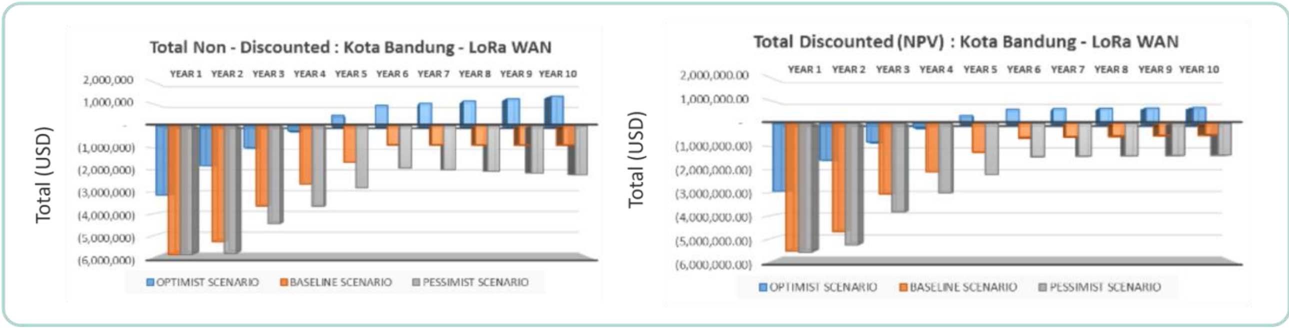


Figure 17. Total Cashflow: Kota Bandung – LoRaWAN for Non-Discounted and Discounted (NPV)

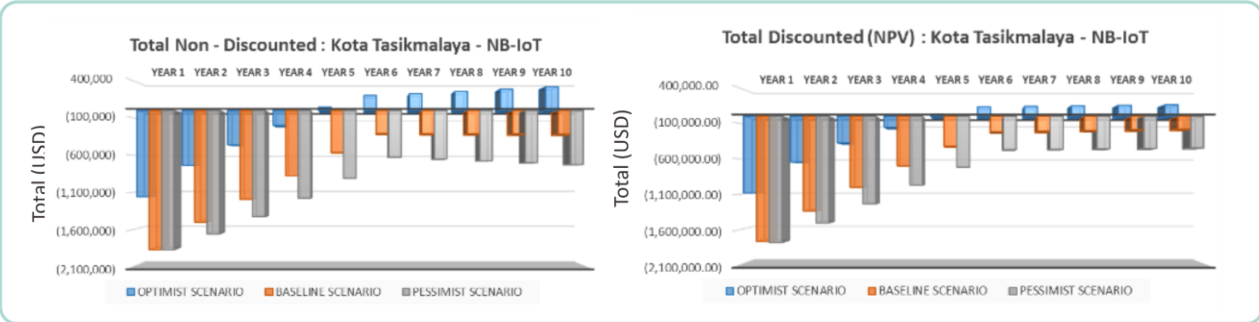


Figure 18. Total Cashflow: Kota Tasikmalaya – NB-IoT for Non-Discounted and Discounted (NPV)

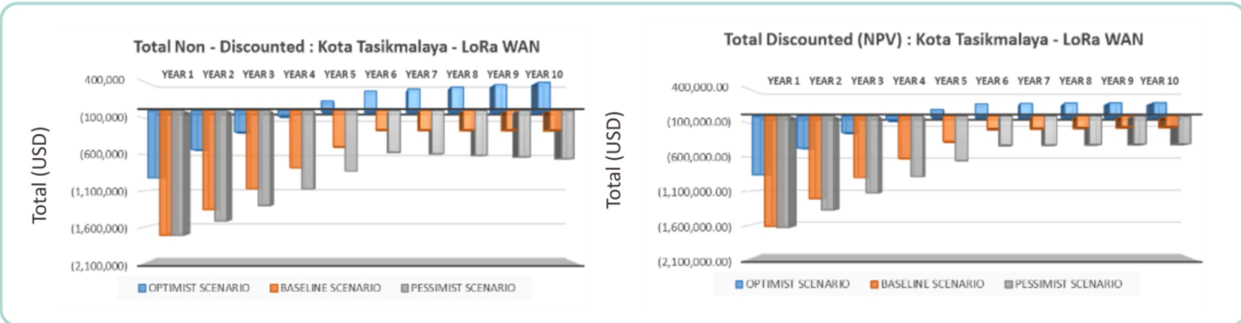


Figure 19. Total Cashflow: Kota Tasikmalaya – LoRaWAN for Non-Discounted and Discounted (NPV)

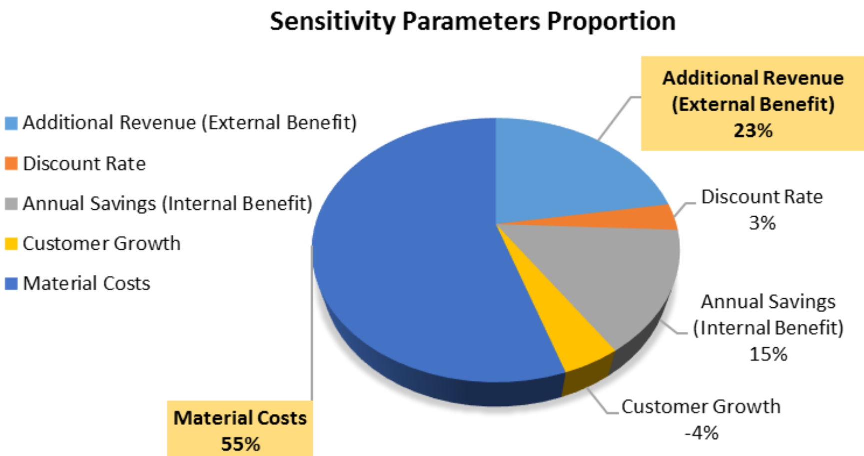


Figure 20. Sensitivity Parameters Proportion

4.4. Selecting The Right Connectivity Technology for Smart Metering

After assessing the technical and economical aspects, it is necessary for PLN as the main actor to choose the right connectivity technology for smart metering deployment. Building a successful IoT solution is all about matching connectivity needs to the right technology or mix of technologies. Whether it chooses one specific network technology or takes a multi-network approach.

The critical decision criteria for smart metering applications will be presented as a recommendation for PLN in determining the most appropriate technology. Nine criteria will be considered for the deployment of the smart meter. They are coverage, capacity, quality of service/data rate/latency, battery lifetime, security, ecosystem maturity, business model, time to market, and total cost.

The analysis can be done using 2 schemes (1) Quantitative: based on previous calculation and simulation, and (2) Qualitative: by referring to several references like an academic journal, research paper, textbook, and survey analysis result (Actility, 2018; Mekki et al., 2018; Vannieuwenborg & Verbrugge, 2018) as shown in Table 15.

Table 15. Key Decision Criteria and Recommendations

No	Criteria and Consideration	Requirements of Smart Meter	Leading Technology		Recommendations and References
			LoRaWAN	NB-IoT	
1	**Coverage**				
	• Geographic Span	National	■	■	NB-IoT is leading in terms of coverage, especially for an urban environment and indoor/deep indoor end node locations. In addition, because NB-IoT utilizes existing cellular infrastructure, the deployment of NB-IoT becomes easier. LoRa is more suitable for rural deployment, especially in fewer LTE sites.
	• Level of Connectivity Required	Indoor / Deep Indoor		■	
	• Urban End Node Location	Yes (Major)		■	
	• Remote End Node Location	Yes (Minor)			
	• Mobility	No (Static)	■	■	
2	**Capacity**				
	• Data Traffic	Small data/No Streaming	■	■	Both technologies can support smart meter capacity requirements, but NB-IoT is leading in terms of base station capacity (Mekki et al., 2018) and less regulatory constraints (duty cycle, power, etc.)
	• Size of the messages (payload)	< 20 bytes	■	■	
	• Number of message/day	± 6 per meter	■	■	
	• Gateway / Base Station Capacity	Higher		■	
3	**QoS / Data Rate / Latency**				
	• Licensed or Unlicensed	Can use both	■	■	Both technologies can support licensed and unlicensed. NB-IoT is preferred for an application that requires QoS because NB-IoT can support a higher data rate than LoRaWAN. However, LoRaWAN actually offers enough data rate and latency requirements for smart metering.
	• Data Rate requirement	Can use both (Appropriate)	■	■	
	• Delay requirement	Delay-tolerant	■	■	
4	**Battery**				
	• Required battery lifetime	#Years (Lower energy consumption)	■		NB-IoT consumes additional energy because of synchronous communication and QoS handling (Mekki et al., 2018), due to less complicated radio and asynchronous nature of the protocol, LoRaWAN is 3-5 times more power-efficient than NB-IoT (Actility, 2018)
5	**Security**				
	• Authentication	More Secure		■	NB-IoT offers a more heavyweight carrier-grade security which is arguably more secure than LoRaWAN
	• Data Transmission	More Secure		■	
6	**Ecosystem Maturity**				
	• Infrastructure readiness	More Mature		■	In Indonesia, NB-IoT is considered to have a more mature ecosystem because the existing LTE infrastructure which has already been deployed, while several countries prefer LoRaWAN (Actility, 2018). NB-IoT is also considered as 3GPP-Standard technology; it has the potential to have a healthy ecosystem in the future
	• Stakeholder readiness (module and meter vendor, network operator, consumer)	More Mature	■	■	

No	Criteria and Consideration	Requirements of Smart Meter	Leading Technology LoRaWAN	NB-IoT	Recommendations and References
7	**Business Model**				
	• Private or Public Network	Private Managed Network	■		It is prefered that smart meter be in privately managed networks to ensure security and high SLA requirements. It strongly depends on the vision of PLN that will run this business.
	• Network Operator Dependencies	No	■		
	• Leasing or Ownership	Ownership	■		
8	**Time to Market**				
	• Network Availability	The higher level of availability		■	NB-IoT can take advantage because the infrastructure is already established (4G LTE). However, it is limited to the existing 4G/LTE base stations. It is not ideal for the rural or suburban region that does not have 4G coverage. LoRaWAN is the alternative-for faster time to market. But it is possible to build a hybrid model.
	• Time to establish an ecosystem	Faster	■		
9	**Total Cost**				
	• Capital Expenditure (Capex)	Lower	■		LoRa is more cost-effective compared to NB-IoT. It is mainly considered from spectrum cost and device cost.
	• Operational Expenditure (Opex)	Lower	■		
	• Return on Investment (ROI)	Faster	■		

Source: (Actility, 2018; Mekki et al., 2018; Vannieuwenborg & Verbrugge, 2018)

5. Conclusion

This study analyses the technology selection of smart electricity metering deployment using two LPWA-based technologies. The results show that both LoRaWAN as a build scheme and NB-IoT as a leasing scheme are technically and economically suitable for typical massive IoT applications like smart electricity metering. In addition, both offer different unique values. LoRaWAN is the leading technology in terms of battery lifetime, business model, time-to-market, and total cost. While NB-IoT is the leading technology in terms of coverage, capacity, quality of service, security, and ecosystem maturity. Both technologies are expected to complement each other and can co-exist in a different environment.

Based on the calculation and analysis conducted in this study, there are also some important findings. First, it has been discovered that when there is no extra charge are imposed to consumers and no requirements of large capacity for data communication, the NPV of the built scheme technology (LoRaWAN) is 23% greater than NB-IoT in year 10. In this condition, LoRaWAN is considered to be the most optimal solution to be implemented by a utility company. In addition, another benefit of built scheme is that the PLN will retain the ownership of the system once the deployment period ends.

Second, by examining the baseline and applying pessimistic scenario, neither LoRaWAN nor NB-IoT is economically feasible for smart electricity metering implementation. It will only be viable if consumers' contribution is considered. Therefore, it may be necessary to re-introduce supporting regulation related to those factors.

Third, NB-IoT, as other candidate technology which is provided by a telecom company can be more attractive if the demand is growing or if the other technical requirements (as shown in Table 15) are more important or have high priority. NB-IoT is significantly potential in several factors provided by the value overpass the simplicity of LoRaWAN.

6. Acknowledgements

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