Design And Simulation Of Solar Power Generation On Rooftops Towards Clean Technology

Samsurizal (1), Nurmiati Pasra *(2), Shidarta Rico Adewijaya (3),
1,3 *Electrical Engineering Department, Institusi Teknologi PLN, Indonesia*
2 *Electrical Technology Department, Institusi Teknologi PLN, Indonesia*
*Email address : **samsurizal@itpln.ac.id**

***Abstract*— Various efforts are continuously being encouraged and pursued in order to achieve the clean energy transition program. The clear goal is to reach a renewable energy mix target of 23% by 2025. The use of electrical energy is increasing each year, but the availability of fossil energy as the majority fuel used in power generation is becoming limited. Indonesia, being located near the equator, experiences high solar radiation intensity. This potential can be utilized for harnessing solar energy as a power source. Additionally, the utilization of solar energy as an alternative source is more environmentally friendly as it reduces emissions from fossil fuel-based power generation. In this research, the design and planning of a solar power plant are conducted to create clean and environmentally friendly energy. The technical aspects are discussed and simulated using software. The author utilizes the Helioscope application for analyzing the feasibility of installing a solar power plant and conducting simulations. Based on the research results, by utilizing a roof area of 13,725 m2 and installing 2,305 solar modules with a capacity of 550 Wp per module, the solar power plant's capacity amounts to 1,267.8 kWp. The performance ratio is calculated to be 80.6%, and the energy production over a year is estimated at 1,695,000 MW.**

Keywords*— *Clean energy, solar energy, building rooftops, solar power generation

I. Introduction

The energy sector significantly contributes to emissions, and energy transition policies need to be implemented prioritizing low-carbon energy sources and technologies. In general, energy transition policies towards broader utilization of clean energy are driven by global concerns about climate change issues. The excessive use of fossil energy over the years has led to increased greenhouse gas (GHG) emissions far beyond the safe limit, resulting in climate change.

Indonesia is a tropical country with two seasons, namely the dry season and the rainy season. Additionally, Indonesia is located near the equator, resulting in constant sunlight throughout the day, although the intensity of sunlight may decrease during the rainy season. Such conditions can be effectively utilized by harnessing solar energy as an alternative energy source in the future. Furthermore, solar power generation is highly environmentally friendly.

With the significant potential for solar energy utilization, it is important to make the best use of this resource. Besides reducing reliance on fossil fuels, solar energy can help reduce emissions from fossil fuel power plants and save costs on electricity expenses that are typically obtained from the national power grid. Currently, the utilization of renewable energy sources is still not optimal. This has prompted the government to prioritize the development of rooftop solar power plants through specific policies. These policies are stated in the Minister of Energy and Mineral Resources Regulation No. 49 of 2018, Ministerial Regulation No. 13 of 2019, and Ministerial Regulation No. 16 of 2019, regarding the use of Roof Solar Power Generation Systems by customers of the State Electricity Company (PLN). These policies provide more business opportunities and flexibility for the renewable energy sector to flourish. Rooftop Solar Power Plants are highly flexible and can be installed on a small scale, such as residential homes and offices, or on a large scale in centralized installations.

There have been several studies conducted on the utilization of solar energy, including [6]. In their research published in the Journal Spektrum, Vol. 8, No. 2, June 2021: 249-256, titled "Design and Simulation of a 1 kWp Rooftop Solar Photovoltaic System Using Helioscope," the focus is on the design of a 1 kWp rooftop solar photovoltaic system and the simulation of its performance using the Helioscope software. The required data includes the location coordinates, type of inverter and solar modules, and the area of the roof for installation. The design involves using 7 units of Canadian Solar 195 Wp panels with a 1 kW AEC inverter, facing north. This solar photovoltaic system can generate an average daily electricity output of 5.48 kWh, with a performance ratio of 73.6% and solar irradiation of 1859.2 kWh/m2.

In another study Samsurizal published in Volume 14, Issue 1, April 2022: 1-6, ISSN 2580-6807, the optimization of the installed Solar Power Plant at PT. PJB Muara Karang Generating Unit is discussed. Based on the conducted simulations, it was found that a total of 143 units of modules can be installed, generating a capacity of 49,000 Wp with an annual production of 93,951 kWh/year[16]. The previous number of installed solar modules was 58 units. The estimated energy generated by the Solar Power Plant is capable of supplying 75.11% of the electricity demand in the building, with an average daily production of 36.27 kWh.

Based on the background and previous research conducted, as well as in support of government policies regarding clean energy, this study aims to assess, design, and install rooftop Solar Power Plants as electricity suppliers at PT. X using the Helioscope software. The objective is to determine the potential electricity generation and feasibility of installing PLTS using the Helioscope software.

II. Methods

In this study, several stages were conducted, which are presented in the research flowchart shown in Figure 1.

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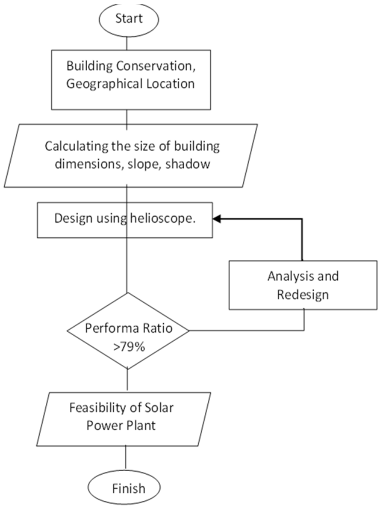

Fig.1 Flowchart of Research

Data Analysis Method, this method can be carried out by analyzing the results of technical and economic studies in data collection and discussions. The technical analysis in this research aims to determine the performance ratio and electricity production results of the planned solar photovoltaic system based on the summary report from the helioscope software.

The design installation of the solar photovoltaic system can be done using web-based software called Helioscope. Folsom Labs is the developer of this application. This application provides users with the ability to create simulation designs with a three-dimensional view. Therefore, users can estimate the shading that will occur, which can be caused by taller buildings or trees. Shading can affect the performance of the solar photovoltaic system, resulting in suboptimal energy generation. Helioscope also has a user-friendly interface that makes it easier for users to create design plans.

The weather data used by Helioscope is sourced from meteonorm and uses Typical Meteorological Year (TMY) weather analysis. TMY weather is a collection of meteorological data at a specific location summarized over a period of 10 years or more. The weather data used to analyze energy production in the Helioscope application is based on monthly average weather data at a specific location.

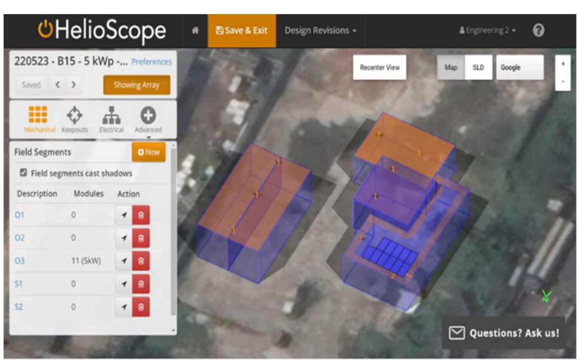

Fig. 2. Helioscope Interface Image

Figure 2 shows the Helioscope interface image, where on the left side, there are several features: mechanical, keepouts, electrical, and advanced. The mechanical feature is used to create building and solar module modeling. Keepout is used to create shadow modeling, such as trees, lightning rods, towers, etc. Electrical can be used to select cables and inverter capacity that align with the planned solar modules. Meanwhile, the advanced feature can be used to estimate the potential shadows that occur on the solar modules. On the right side of the image is the workspace for integrated design using Google Earth. This allows the design to appear more realistic as it is created on top of buildings found in Google Earth. After completing the building and solar module modeling, there is a feature in the top right corner for creating a Single Line Diagram (SLD).

In the planning of installing the on-grid solar photovoltaic system at PT. X, the selection of solar module type will greatly affect the amount of energy that can be produced by the PLTS system. For this installation, the research has chosen to use Trina Solar TSM-DE19 solar modules with a capacity of 550W, specifically the monocrystalline type. This selection is based on the desired high capacity. Therefore, the monocrystalline module type was chosen to ensure higher and more efficient energy generation from the PLTS. Additionally, monocrystalline panels are chosen for their advantage of having smaller cell arrangements, allowing for faster conversion of sunlight into electrical energy. Figure 3 represents an image of the solar module.

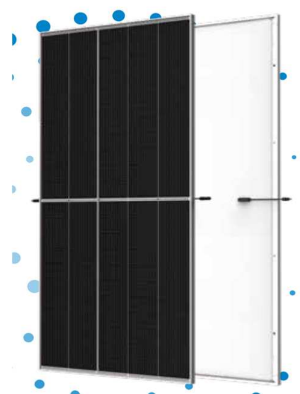

Fig.3. Solar Module

TABLE 1. THE ELECTRICAL SPECIFICATIONS OF A SOLAR MODULE TYPICALLY

Efficiency	
Modul Efficiency (%)	21
Electrical Data	
Peak Power Watts-Pmax (Wp)	550
Maximum Power Voltage - VMPP (V)	31,6
Maximum Power Current - I MPP (A)	17,4
Open Circuit Voltage - VDC (V)	37,9
Short Circuit Current - Isc (A)	18,52

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In selecting the inverter, the author chose a three-phase inverter, which is currently widely available in the market. It is essential to choose a certified inverter to facilitate equipment selection. The decision to opt for a three-phase inverter is based on the electrical installation system used at PT. X, which also utilizes a three-phase system. The specific model of inverter chosen for this planning is the Huawei SUN2000-100KTL-M1 with a power rating of 100 kW.

The selection of this inverter is based on its capacity that closely matches the installed capacity of the solar photovoltaic system). In this planning, the installed solar photovoltaic system capacity is quite large, specifically 1.2 MW. This allows for effective utilization of the required number of inverters. Additionally, the choice of the Huawei SUN2000-100KTL-M1 inverter is also based on its high efficiency and compatibility with various solar module brands. Figure 4 represents an image of the Huawei SUN2000-100KTL-M1 three-phase inverter.

Fig.4. Three-phase inverter

TABLE 2. SPECIFICATIONS OF A THREE-PHASE INVERTER HUAWEI
HUAWEI SUN2000-100KTL M1

Efficiency	
Inverter Efficiency (%)	98,8% @480V, 98,6% @380V/400V
Input	
Max input Voltage (V)	1100
Max. Current per MPPT (A)	20
Max. Short Circuit per MPPT (A)	40
Start Voltage (V)	200
MPPT Operating Voltage Range (V)	200-1000
Nominal Input Voltage	720V @480 Vac, 600V @400 Vac. 570V @380Vac
Number of MPP Tracker	10
Max Number of Inputs	20
Output	
Efficiency	
Max AC Apparent Power (VA)	1100
Max. AC Active Power (cos phi=1) (W)	20
Nominal Output Voltage (A)	40
Rated Grid AC Frequency (V)	200
Nominal Output Current (V)	200-1000
Max. Output Current	720V @480 Vac, 600V @400 Vac. 570V @380Vac
Number of MPP Tracker	10
Max Number of Inputs	20

III. Results and Discussion

This research was conducted by first determining the location and coordinates of the solar photovoltaic system at PT. X that will be installed. The location area at PT. X can be seen in Figure 5 below.

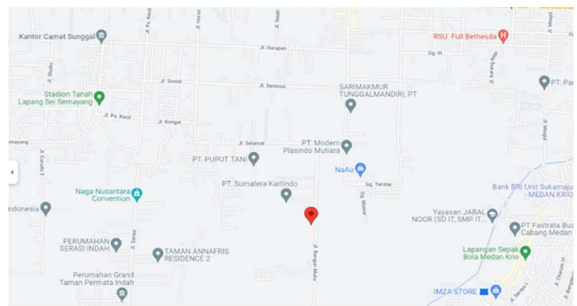

Fig. 5. Research location

With the known location, weather data can be obtained. Table 3 shows the monthly average weather data obtained using meteonorm. This data serves as a reference used in the Helioscope application.

TABLE 3. METEONORM WEATHER DATA

Moon	**Global Horizontal Irradiance (kWh/m²/hari)**	**Horizontal Diffuse Irradiation (KWh/m²/hari)**	**Global Horizontal Irradiance (kWh/m²/bulan)**	**Horizontal Diffuse Irradiation (KWh/m²/bulan)**	**Temperatur °C**	**Kecepatan Angin (m/s)**
January	4.22	2.37	129.5	73,4	26,8	1,6
February	4.67	2.84	128.1	79,4	27,2	1,59
Marct	4.96	2.82	153.7	87,6	27,6	1,7
April	4.82	2.73	142.7	82	27,4	1,49

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Moon	Global Horizontal Irradiance (kWh/m^2/hari)	Horizontal Diffuse Irradiation (KWh/m^2/hari)	Global Horizontal Irradiance (kWh/m^2/bulan)	Horizontal Diffuse Irradiation (KWh/m^2/bulan)	Temperatur °C	Kecepatan Angin (m/s)
May	4.68	2.46	144.7	76,2	27,9	1,6
June	4.67	2.61	138.3	78,3	27,4	1,5
July	4.72	2.28	146.0	70,5	27,5	1,59
Augt	4.53	2.73	143.2	84,5	27,4	1,6
Sept	4.32	2.46	132.3	73,9	26,5	1,5
October	4.72	2.68	142.3	83,1	26,7	1,4
November	4.12	2.19	127.0	65,7	26,4	1,49
December	4.00	2.19	121.0	67,9	26,7	1,5

Based on Table 3, the weather data compiled by Meteonorm is provided. The global horizontal irradiance represents the radiation value at a specific location, combining direct solar radiation with the radiation reflected from clouds. On the other hand, the horizontal diffuse irradiation refers to the radiation value considering only the reflection from clouds. As a result, the horizontal diffuse irradiation value is lower than the global horizontal irradiance value. Additionally, Table 3 also includes average temperature and wind speed data. The values of global horizontal irradiance and horizontal diffuse irradiation in Table 3 represent the average daily radiation values for each month.

The photovoltaic system planned in this study will be installed with a capacity of 1,268 kWp. Therefore, the solar photovoltaic system will be installed at 36.59% of the total installed power, which is 3,465 kVa. According to Regulation of the Minister of Energy and Mineral Resources (ESDM) No. 49 of 2018, the maximum capacity of the rooftop system that can be installed is 100% of the total power connected by PLN customers[5]. Hence, the capacity of the solar photovoltaic system can still be maximized in the future if necessary.

There are two options for the installation planning of the photovoltaic system. The first option is to install the solar photovoltaic system according to 100% of the installed power capacity of PT. X, which is 3,465 kW (Ministerial Regulation ESDM No. 49, 2018). The second option is to install the PLTS based on the consumption load requirements (Ministry of Energy and Mineral Resources (KESDM), 2018)[5]. In this study, the PLTS is planned to be installed using the second option, which is based on the consumption load requirements. The recommended capacity of the PLTS is not taken from the average peak load (WBP) value but based on the off-peak load (LWBP) value. This is because the solar photovoltaic system does not operate during the peak load period. The average load consumption per hour during LWBP can be calculated by dividing the total load consumption value in one month by the number of days, and then dividing it by the duration of LWBP, which is 19 hours. Consequently, the average hourly electrical energy consumed by the load can be obtained.

To determine the capacity of the solar photovoltaic system, it is calculated by dividing the lowest average LWBP value by 1.1 and then multiplying it by 1.2. Here, 1.1 represents the tolerance value standard, and 1.2 is the DC/AC Ratio value. The recommended installation capacity of the PLTS is based on the lowest average LWBP value so that the electrical energy production Modeling includes the design of buildings A and B, skylights, blowers, stairs, and lightning rods. Figure 7 shows the modeling of solar power plants in building A and building B to be installedgenerated by the PLTS can be fully absorbed by the load. Therefore, if it is installed based on the highest load consumption, there is a possibility that on certain days the electrical consumption by the load will be low. Consequently, the electrical energy generated by the PLTS will not be utilized. This unused electrical energy can be exported to the power grid (PLN) at a price per kWh of 65% of the normal PLN price. However, it is advisable to minimize this as much as possible since it is only valued at 65% of the normal price by PLN. The plan to install solar roofs is presented in figure 5, where solar roofs will be placed in buildings A and B.

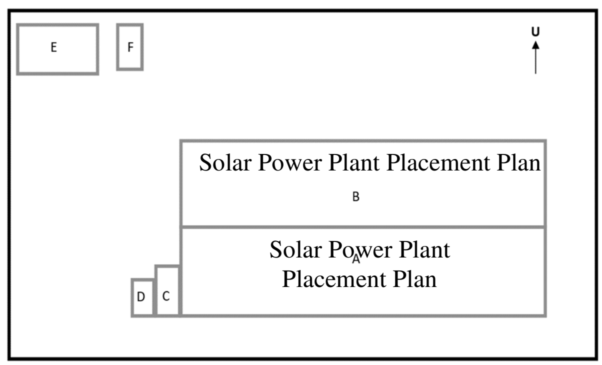

Fig. 6. Solar roof placement area plan

Modeling of the data obtained using the Helioscope.

Modeling includes the design of buildings A and B, skylights, blowers, stairs, and lightning rods. Figure 7 shows the modeling of solar power plants in building A and building B to be installed.

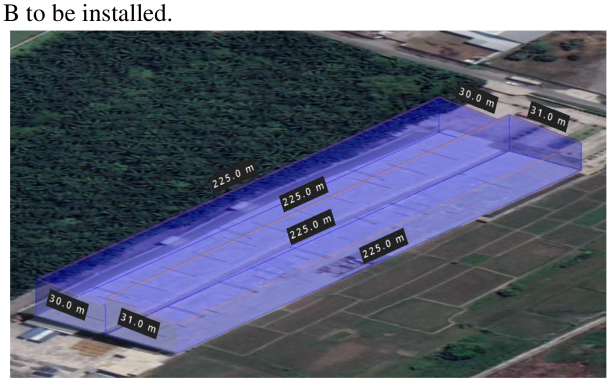

Fig.7. Building side view

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Based on Figure 7, the size of the roof area to be used for the rooftop photovoltaic system (PLTS) is determined to be 13,725 m^2. The array modeling is done using Helioscope by inputting data such as the brand and capacity of the solar modules. Then, the array modeling is manually inputted. The location selection for placing the solar modules on the roof is done according to the existing roof conditions. The modules are installed on areas of the roof without potential shading objects to avoid affecting the module's performance. Additionally, the solar modules should not be installed in areas that could hinder the performance of other objects, such as skylights. Solar modules should not cover skylights as it would disrupt the skylight's own performance. Figure 8 illustrates the process of inputting solar module data in the Helioscope application.

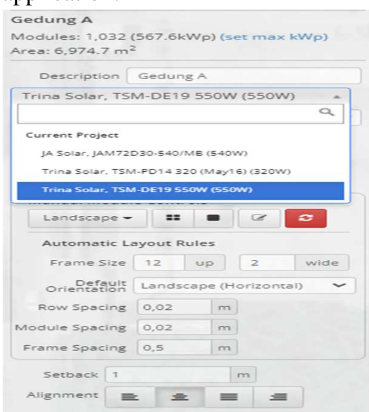

Fig. 8. Solar Module Brand

Figure 8 shows the application interface when inputting the brand of the solar modules. After modeling the building, skylights, blowers, stairs, and lightning rods, the author proceeds to input the solar modules to be used. Following that, the author creates the array modeling with a module spacing of 0.02 meters and a minimum distance of 1 meter from the roof edge. The next step, as shown in Figure 9, presents the results of the array modeling using the Helioscope application, where the placement of solar modules is adjusted to the roof conditions.

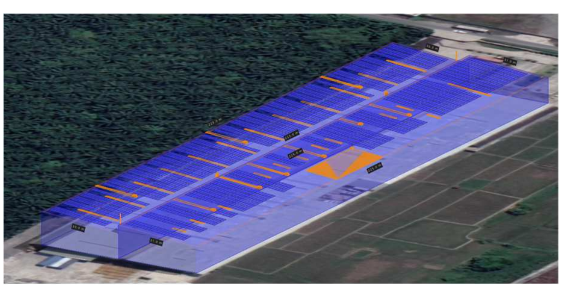

Fig. 9. Array Modeling Results

The determination of the placement of solar modules in the above Figure 9 is done by selecting a roof location with minimal shading and without obstructing specific objects on the roof, such as skylights. This is done to ensure that the objects on the roof are not affected in their functionality and that the solar photovoltaic (PV) system can generate maximum energy. By considering the existing objects on the roof, the author can plan the placement of solar modules in a way that avoids shading from those objects or even prevents the modules from covering them, such as skylights. This is done to ensure that the skylights can continue to function as intended. As seen in the above figure, the author did not place the solar modules directly over the skylights but positioned them between two skylights.

After the solar modules are installed, the next step is to input the brand and capacity of the inverters according to the predetermined specifications. The number of inverters in each building depends on the installed capacity of the solar PV system in each building. Building A requires five inverters, while Building B requires six inverters. Therefore, a total of 11 inverters are needed for this planning. Figure 10 shows the interface of the application when the author is inputting the brand of the inverters to be used. In addition to inputting the brand, the author can also input the quantity of inverters.

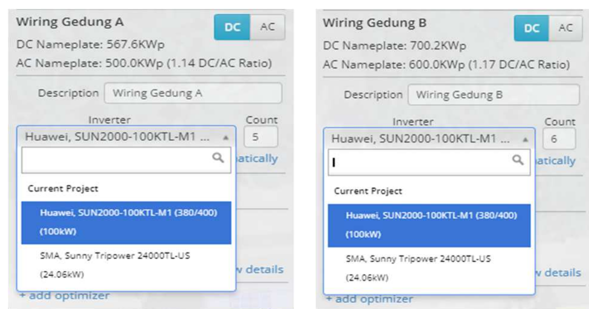

Fig. 10. Input Brand and Capacity of Building A and B Inverters

inverter used in this planning is Huawei SUN2000-100KTL-M1. According to the guidebook released by Helioscope with the title "Understanding DC AC Ratio Helioscope", it is very rare for PLTS arrays to produce energy above 80% or 90% of the DC power value of the module. Thus, using inverter capacity below the capacity of solar modules is one way that can be used because it is profitable. It is called profitable because the PLTS system will have an ideal DC/AC ratio with minimized power loss. The ideal DC/AC ratio is around 1.25%. [4]

Using an inverter with a capacity of approximately 80% of the total installed solar module capacity can save the photovoltaic system installation costs. Because, by increasing the capacity of the inverter without increasing the capacity of the module, it will have no effect on the electrical energy produced. Using an inverter capacity higher than the capacity of the solar module can be done if in the future there are plans

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to add more solar panels installed. The results of PLTS energy production based on the design with Helioscope, obtained through automatic calculations from the Helioscope application. Weather data used for analysis of electrical energy production results is weather data from meteonorm. The estimated data on PLTS energy production in 12 months is shown as shown in figure 11.

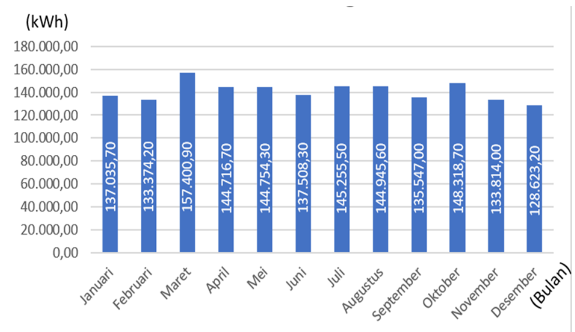

Fig. 11. Estimated Solar Production Results in 12 Months

Estimates of the energy production from the photovoltaic system can be influenced by weather conditions, solar irradiation, air temperature, and solar radiation intensity based on weather data obtained through Meteonorm for the installation location of the PLTS. Additionally, it can also be affected by the ambient temperature around the location, which can impact the temperature of the solar panels. Higher air temperatures result in an increase in the temperature of the solar panels, leading to decreased and suboptimal performance in energy production from the panels.

IV. Conclusion

Based on the results obtained from the research, several conclusions can be drawn, including. With a roof area of 13,725 m2, the installed solar module capacity is 1,267.8 kWp. The total number of installed modules is 2,305 units, with 11 installed inverters. The Performance Ratio, based on the data obtained from the Helioscope application, is 80.6%, with an annual production value of 1,695,000 MW. The average monthly energy production on the building's roof is 141,269.7 kWh. Therefore, it can be concluded that the PLTS with a capacity of 1,267.8 kWp to be installed on the roof of PT. X is deemed suitable for installation from a technical aspect.

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