Utilization of technology and digitalization to bring equality energy access for remote areas

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Abstract. More electricity infrastructures to serve off-grid or mini-grid solutions have been installed to become the best choice for rural areas to increase the electrification ratio. The Indonesian government uses this ratio as a primary indicator for measuring the range of energy supply. The electrification ratio of Indonesia reached 99.2% in 2020. However, this seemingly bright achievement must be followed by improving the quality of access to electricity. The solution to this challenge is digital transformation to modernize data and perform analysis in the network ecosystem to create an intelligent utility system that will improve the quality of access to electricity. The simulation of the utilization of SEMons shows a significant decrease in the LCOE (Levelized Cost of Energy) of the solar PV power plant of around 14.52% compared to the existing condition with the manual monitoring method. For the units built-in 2017, there is a reduction of LCOE from 0.1034 USD/kWh to 0.0866 USD/kWh. This decrease in the LCOE value indicates a reduction in fixed Operation & Maintenance costs due to the optimized predictive maintenance to improve the availability of units.

1. Introduction
Geographical diversity becomes a challenge for archipelago countries like Indonesia to provide grid electricity in the distant future. Indonesia, consisting of tens of thousands of islands, faces inequitable energy access, especially in electrification for 3T (outermost, foremost, and disadvantaged) regions where the vast majority of the unelectrified population resides. On the other hand, Indonesia's electricity demand increases due to social and economic developments. Based on The National Electricity Supply Business Plan (RUPTL) 2019-2028, the electricity demand will reach 433 Terra Watts Hour (TWh) in 2028, with an average growth of 6.42% over ten years. To respond to this phenomenon, the government targeted an acceleration installation program of 56.39 GW of additional power generation by 2028. Power generation in Indonesia is currently dominated by fossil fuels and is predicted to remain the primary energy source until 2028. However, efforts to reduce the contribution of fossil fuels continue to be made to meet Indonesia's commitment to reducing greenhouse gas emissions (GHG) by 29% (834 million tons CO₂) by 2030. One of the efforts to achieve this is allocating 30% of the 56.39 GW of additional installations for the renewable power plant. It is a part of efforts to support an energy mix target for new and renewable energy (NRE) of 23% in the primary energy mix by 2025.

Indonesia aims to reduce its greenhouse gas (GHG) emissions by 29% (or 41% with international support) compared to the Business as Usual (BAU) scenario by 2030. As one of the sectors contributing to GHG emissions, the energy sector is also the second-largest emitter in Indonesia, contributing around 40% of total emissions between 2010 to 2018. Emissions from the energy sector are predicted to increase...
to 58% by 2030, as indicated under the BAU scenario in Indonesia’s Nationally Determined Contribution (NDC), mainly driven by the increase in the final energy consumption. The projection is in line with the trend in emission intensity, where GHG emissions per final energy consumption have not significantly improved in the last decade.

Based on that aim, Solar PV is one of the alternative ways to substitute or even replace fossil-fueled power plants. In addition to the increasingly limited fossil energy sources, fossil-fueled power plants release CO$_2$ due to fossil energy combustion. CO$_2$ is one of the GHG emitters (Waskito, 2011). The rate of reduction of greenhouse gases (GHG) by implementing the one kWp Solar PV system is estimated to be around 1.66 kg SO$_2$; 3.46 kg NO$_x$; 1 295 kg CO$_2$; and 91 kg of ash per year.

Around 29 solar PV power plants spread across seven districts with a total capacity of 750 kWp serving 2,224 households have been built in one of the outermost provinces in the 2012-2017 period to support the energy mix program. However, it is difficult for the government to maintain and monitor the power plants because of their difficult-to-reach locations. The lack of technical capacity leads to underutilized units as well. Therefore, utilizing technology and digitalization through Smart Energy Monitoring System (SE Mons) is hoped to solve the problems above. This paper aims to analyze the financial impact of the application and implementation of this technology in existing solar PV power plants by lowering LCOE as an indicator of energy generation costs.

SE Mons is an integrated energy management platform that helps renewable energy power plants user with automated data reading and real-time actionable insight along the production line and supply chain in one. It allows users to analyze better, predict and proactively act before issues arise to achieve flawless operation. It includes online monitoring, analyzing, reporting, controlling, maintenance, production management, prediction, and other functions. It contains several sensors to collect data from renewable energy power plants: DSM501A dust sensor, DHT11 Therma sensor, ACS712 current sensor, and Voltage Divider connected to Micro Single Board Arduino UNO and WiFi Module ESP8266.

In a remote monitoring system, the parameters of the solar PV system are measured by sensors and processed by signal processors. The information is sent electronically to a central location where the operator can monitor and take appropriate action when needed. The primary remote monitoring system consists of a transmitter at the remote site (where the solar PV system is installed) and a receiver at the central station (from where the solar PV system monitoring process is done). Transmitter and receiver can be small embedded systems or can be computer-based systems. According to the remote location and the type of system used by the central station, remote monitoring systems can be divided into several categories: (1) Computer (remote) to a computer (central) remote monitoring system, (2) Embedded system (remote) to a computer (central) remote monitoring system, (3) Embedded system (remote) to embedded system (central) remote monitoring. Table 1 lists the remote monitoring systems implemented in different ways, compared with the total cost of SPV systems and their annual initial and recurring/operating costs.

| No | System Technology | Cost of remote monitoring system (initial + operating) (%) |
|----|------------------|----------------------------------------------------------|
| 1  | Computer to computer Ethernet | 25 |
| 2  | Embedded system to computer based GPRS – GSM | 22 |
| 3  | Embedded system to embedded system GPRS - Mobile | 13 |
2. Methodology
The research employed mixed methods of a qualitative and comparative approach in working with installation in the rural areas, including a rural electrification map to analyze the existing condition. This study began by selecting one of the outermost provinces in Indonesia, which received a grant for a solar PV power plants development program from the Indonesian government. Based on the data of the Ministry of Energy and Mineral Resources of the Republic of Indonesia, the electrification ratio of that particular province has reached 99%. The data of the solar power plant in the selected region is used to analyze the utilization of technology and digitalization by using the method of LCOE (Levelized Cost of Energy).

2.1. Levelized Cost of Energy (LCOE)
LCOE is a measurement used to assess the overall cost of each alternative electricity generation technology with total electricity generated by a unit over an assumed lifetime. The assessment results in a value representing the energy-producing technological option for the decision-making process. The concept is related to assessing net-present value to determine whether a project will be a worthwhile investment in financial terms. It can be done by first taking the net present worth of the initial cost of investments and operating/maintenance the power generating asset. The total cost will be converted into an equivalent annual cost. The total electricity generated is counted as the average annual electricity generation. Capital expenditure (CAPEX), commonly called investment cost, is one of the critical parameters in calculating LCOE, which is often used to compare different technologies. The CAPEX accumulates the costs of the direct investments of the unit, which could be in the form of installation cost, equipment cost, and project preparation cost. Operation and maintenance (O&M) costs account for the recurring generated energy costs associated with equipment operating and maintenance. The two main components in operation expenditure (OPEX) are fixed and variable O&M costs. In planning the financing of solar PV installations, operational costs are commonly calculated at 0.6% of the total investment costs of the solar PV plant (Kaltschmitt, 2007). The variable O&M cost is almost negligible, while fixed O&M cost is kept constant across the whole lifetime.

Capacity factor (CF) is a ratio of the total actual energy produced of a power plant with the theoretically maximum possible energy produced over a definite period. Each location has unique solar irradiation and causes different CF, which directly affects the availability of the resources. The higher the CF, the more electricity generated, and the lower the LCOE. The table below summarizes a capacity factor from various sources (in %).

Table 2. Capacity factor of various power plant type.

| Power plant type     | NEC 2017 | BNEF 2018 | Survey | RUPTL |
|----------------------|----------|-----------|--------|-------|
|                      | Low | High | Low | High | Low | High |       |       |
| Geothermal           | 70  | 100 | 70  | 80  | -   | 98  | 73    |       |
| Mini/micro hydro     | 50  | 95  | 23  | 50  | 65  | 71  | 32    |       |
| Large hydro          | 20  | 95  | -   | -   | -   | -   | -     |       |
| Solar PV large scale | 14  | 22  | 14  | 17  | 16  | 20  | 7     |       |
| Wind                 | 20  | 45  | 21  | 25  | -   | -   | 26.5  |       |
| Biomass              | 67  | 77  | 70  | 85  | 35  |     |       |       |
| Coal                 | 51  | 51  | 80  | 80  | 57  |     |       |       |
| Gas                  | 50  | 50  | -   | -   | 37  |     |       |       |

(Source: Levelized Cost of Electricity in Indonesia: Understanding the Levelized Cost of Electricity Generation, 2019)
This method is applied by calculating the investment cost as cost unit per kW and corresponds to all expenses that occurred during the development phase of the power plant. Some assumptions used in the calculation are ongoing annual operating costs with 30 years lifetime and a 10% discount rate that produce a constant value of capital recovery factor over the plant's lifetime. Finally, by summing all the costs and dividing the results with total electricity generated, it will give the LCOE value of the proposed technology. Comparative analysis is carried out by comparing the LCOE value of the solar PV power plant units that have been built with the addition of digitalization technology for monitoring, namely SEMons.

2.2. Smart Energy Monitoring Systems (SE Mons)

SE Mons can collect performance data from renewable power plants, processes it, and send it to cloud servers. It could be the solution to the main challenges of renewable energy integration to establish an optimal balance between supply and demand. It can potentially be applied by employing advanced IoT that can help facilitate and speed up the integration by providing reliable consumption trends and predicting the performance of technologies. The flexibility is provided by the demand-side response to integrate renewable energy resources of supply following demand.

SE Mons can take predictive analytics to the next level to manage the units more efficiently and effectively. Those data allow effective predictive maintenance and performance monitoring of solar PV power plants. It will lead to customize analytics for better decisions and optimized performance. Furthermore, using more sophisticated digital tools, data analytics, and visualization software will drive better management, including replacing traditional metering with smart-measuring technology combined with machine learning capabilities. The main drivers of the digitalization strategy in analyzing, understanding, and predicting energy use are increasing business efficiency and effectiveness, reducing costs, producing new products, and the most important thing is improving the capability of locals.

3. Results

The data of 29 solar PV power plants that spread throughout the selected province was used to calculate the value of LCOE. Some main parameters needed in this analysis are final capital cost, fixed and variable O&M, capacity factor, discount rate, and technical lifetime. The investment cost is calculated by considering all costs needed during the development stage, feasibility study, human resources, component, permit, and certification. O&M cost is calculated from the average solar PV power plant cost for one year and, an operating lifetime of 30 years is assumed. The value of the capacity factor is in the range of 16-20%. The value of this capacity factor is very dependent on the solar PV power plant.
condition, availability, technology, forced outage rate, and scheduled outage factor. Furthermore, to calculate the feasibility of digitalization of the monitoring process, LCOE calculations are carried out by adding investment for SEMons equipment which increases the investment costs, but on the other hand, reduces maintenance costs so that the availability of solar PV power plant can increase. A summary of the LCOE calculations is shown in the graph below.

Table 3. Number of units installed and capacity.

| Year built | No of units | Capacity (kWp) | Household(s) |
|------------|-------------|----------------|--------------|
| 2012       | 1           | 15             | 71           |
| 2013       | 7           | 105            | 265          |
| 2014       | 7           | 185            | 561          |
| 2015       | 2           | 30             | 182          |
| 2016       | 7           | 245            | 1145         |
| 2017       | 5           | 170            | 0            |
| Total      | 29          | 750            | 2224         |

Figure 2. The installed capacity in each year.

Table 4. Percentage decrease of LCOE after utilizing SEMons.

| Year built | Number of units | Total capacity (kWp) | LCOE ($/kWh) | Percentage decrease (%) |
|------------|-----------------|----------------------|--------------|-------------------------|
|            |                 |                      | Without SEMons | With SEMons             |                         |
| 2012       | 1               | 15                   | 0.3079       | 0.2682                  | 12.88%                  |
| 2013       | 7               | 105                  | 0.2796       | 0.2493                  | 10.80%                  |
| 2014       | 7               | 185                  | 0.1932       | 0.1600                  | 17.18%                  |
| 2015       | 2               | 30                   | 0.1146       | 0.0936                  | 18.31%                  |
| 2016       | 7               | 245                  | 0.1060       | 0.0936                  | 11.70%                  |
| 2017       | 5               | 170                  | 0.1034       | 0.0866                  | 16.25%                  |
These results indicate that the use of SEMons can reduce the value of LCOE in each solar PV power plant unit built in the period 2012-2017. And the average decrease in LCOE is around 14.52%. Solar PV power plants do not produce greenhouse gases or air pollution. Solar energy can have indirect-positive effects on the environment since it reduces other energy sources that have more significant effects. Furthermore, solar PV electricity has extensive social and governmental support, as, during its operation, no harmful emissions are released.

Over the whole life-cycle of a solar PV system, it pays back the energy invested and greenhouse gas (GHG) emissions released during its production multiple times. The extended operating period of solar PV systems creates considerable benefits from replacing high-environmental impact electricity from fossil fuels. The electricity delivery over up to 30 years lifetime makes a significant time-lag between the investments regarding cumulative energy demand and greenhouse gas emissions. The rate of reduction of greenhouse gases (GHG) emissions by implementing the one kWp PLTS system is estimated to be around 1.66 kg SO\text{2}; 3.46 kg NO\text{x}; 1 295 kg CO\text{2}; and 91 kg of ash per year. Table 5 below shows the total decrease contribution of GHG (in kg/year) with 1,245 kg SO\text{2} per year, 2,595 kg NO\text{x} per year, 971,250 kg CO\text{2} per year, and 68,250 kg ash per year.
Table 5. GHG decrease contribution.

| No | Year built | GHG decrease contribution (kg/year) |
|----|------------|-------------------------------------|
|    |            | SO₂      | NOₓ      | CO₂     | Ash     |
| 1  | 2012       | 25       | 52       | 19,425  | 1,365   |
| 2  | 2013       | 174      | 363      | 135,975 | 9,555   |
| 3  | 2014       | 307      | 640      | 239,575 | 16,835  |
| 4  | 2015       | 50       | 104      | 38,850  | 2,730   |
| 5  | 2016       | 407      | 848      | 317,275 | 22,295  |
| 6  | 2017       | 282      | 588      | 220,150 | 15,470  |
|    | Total      | 1,245    | 2,595    | 971,250 | 68,250  |

4. Conclusion
The digital transformation in the whole cycle of the renewables power plant allows for automation of different work processes, such as controlling the systems remotely. Platforms for monitoring renewable energy plants will visualize the real-time readings of the operation of each one of the devices that are part of the plants, managing them more effectively and cost-efficiency. It can bring immediate value to the systems to work autonomously, act faster, minimize mistakes, and reduce operating expenses. The utilization of digitalization technology for monitoring shows a positive impact to reduce electricity generation costs due to the increased availability of units. This Integrated service with Hi-tech equipment and highly skilled expert for renewable energy systems offers a one-stop, end-to-end solution for installation owners, governments, and residents through the SEMons.

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