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Implementation of IoT in Smart City Management to Improve Energy Efficiency

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ABSTRACT

The rapid growth of urbanization in Palembang, South Sumatra Province, poses challenges in the management of energy resources and the environment. This study aims to evaluate the application of Internet of Things (IoT) in the E-Cleanness City Information and Management System program as a solution in improving energy efficiency and smart city operations. Mixed research methods were used, combining quantitative and qualitative analysis to obtain a comprehensive picture of the impact of IoT implementation. The results showed a 10% decrease in energy consumption and a 15% increase in operational efficiency after IoT implementation. The main factors contributing to the efficiency improvement include optimization of waste collection routes, reduction in the number of operational vehicles, and improved response times. In addition, user and system manager satisfaction surveys indicated high levels of satisfaction, indicating positive acceptance of the technology. The social and economic benefits include reduced operational costs, improved quality of life, creation of new jobs, and increased environmental awareness. However, challenges such as limited technological infrastructure, the need for further training, complex system integration, and data security and privacy issues need to be addressed to optimize IoT implementation. This research recommends infrastructure development, intensive training programs, and implementation of strong data security protocols as strategic steps to support the sustainability of smart city management in Palembang. The findings are expected to serve as a reference for the development of similar policies in other cities in Indonesia in an effort to achieve energy efficiency and environmental sustainability through IoT technology.

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INTRODUCTION

Rapid population growth and increasing urbanization have become major challenges for many cities in Indonesia. This phenomenon raises various problems related to resource management, infrastructure, and the environment. In this context, the concept of smart cities emerges as an innovative solution to overcome these challenges through the utilization of information and communication technology. A smart city is an approach that integrates various urban systems and services using advanced technology to improve citizens' quality of life, operational efficiency, and environmental sustainability (Ullah et al., 2023). Smart city management

involves various aspects such as transportation, energy, water, waste, and security that are managed in an integrated and data-driven manner.

One of the key technologies in smart city development is the Internet of Things (IoT). IoT enables connectivity and communication between devices spread throughout the city, allowing real-time data collection and faster and more accurate decision-making (Yaacoub & Alouini, 2021). With IoT, various devices such as sensors, cameras, and actuators can interact with each other to optimize city functions. The application of IoT in energy management is one of the crucial aspects in an effort to improve energy efficiency in smart cities. Through IoT, energy usage can be continuously monitored, analyzed, and optimized to reduce waste and reduce operational costs. This technology also supports the implementation of a more efficient and integrated renewable energy system.

Energy efficiency plays an important role in smart city management, especially in the face of climate change and environmental sustainability issues. By improving energy efficiency, cities can reduce carbon emissions, lower fossil energy consumption, and increase the use of renewable energy sources. This not only provides economic benefits, but also a positive contribution to environmental preservation (Faris, 2024). Palembang, as the capital city of South Sumatra Province, is one of the cities experiencing significant urbanization growth. The city has great potential to develop into a smart city through the implementation of various innovative technologies, including IoT. Palembang's success in implementing smart city solutions can serve as an example for other cities in Indonesia.

In its quest to become a smart city, Palembang has launched various programs and initiatives. One notable program is the E-Cleanness City Information and Management System (E-Cleanness). This program is designed to improve the cleanliness and environmental management of the city through the utilization of information and communication technology. E-Cleanness is an integrated system that combines various data and information related to city cleanliness, such as waste management, street cleanliness monitoring, and waste handling. The system uses sensors and IoT devices to collect real-time data, which is then analyzed for more effective and efficient decision-making (LIU, 2024).

The integration of E-Cleanness with IoT technology allows Palembang to monitor and manage aspects of city cleanliness more optimally. Sensors installed at various strategic points of the city can detect waste levels, air quality, and other environmental conditions in real time. This data is then used to optimize waste collection routes, improve cleaning infrastructure, and improve responses to environmental problems (Gobai et al., 2021). While E-Cleanness has made significant contributions to urban hygiene management, there are still challenges that need to be overcome. Some of these include limited technological infrastructure, lack of integration between systems, and the need for more in-depth data analysis to optimize energy use. Therefore, the application of IoT in this program becomes very relevant to overcome these obstacles.

METHODOLOGY

The research with the title “Implementation of IoT in Smart City Management to Improve Energy Efficiency” which focuses on the implementation in Palembang through the E-Cleanness City Information and Management System program uses mixed methods research. This approach combines quantitative and qualitative methods to provide a more comprehensive understanding of the phenomenon under study. In this research, the design used is a secondary explanatory design, where quantitative data is collected first to identify trends and patterns, then supplemented with qualitative data to explain the findings in more depth.

The data collection methods in this study include quantitative and qualitative data. Quantitative data was obtained through secondary data collection from Palembang city government reports, energy consumption data before and after IoT implementation, and operational data from the E-Cleanness program. In addition, the utilization of IoT sensors in this system allows real-time data collection related to energy consumption, cleanliness level, and other environmental parameters. Surveys were also conducted with users and system managers to obtain numerical data on the effectiveness and efficiency of using IoT in energy management. Meanwhile, qualitative data was collected through in-depth interviews with government officials, technicians who manage IoT systems, and Palembang residents to understand the perceptions, challenges, and benefits of IoT implementation. In addition, Focus Group Discussions (FGDs) were held with various stakeholders to gain greater insight into the implementation and its impact. Observation was also conducted by directly observing the operation of the E-Cleanness system and the interaction between IoT technology and city infrastructure.

In analyzing the data, this study used quantitative and qualitative analysis techniques. Quantitative analysis was conducted with descriptive statistics to describe data on energy consumption, operational efficiency, and other environmental parameters. In addition, regression analysis was used to identify the relationship between IoT implementation and energy efficiency improvement, while time series analysis was used to see the trend of energy data over a period of time. Qualitative analysis was conducted using a thematic analysis approach to identify key themes from the interviews and FGDs to understand the factors that influence the success of IoT deployment. To increase the validity of the findings, data triangulation was conducted by combining multiple sources of information. Validity and reliability of the research were also considered by ensuring internal and external validity, so that the research covers various aspects and can be

generalized to other contexts. Instrument reliability was tested through the consistency of the measurement tools used, such as survey questionnaires and interview guides, to ensure the accuracy of the data obtained.

RESULTS

Based on the mixed research methods previously described, this research produces various findings that support the application of IoT in smart city management to improve energy efficiency in Palembang through the E-Cleanness City Information and Management System program. The research results are presented in the form of quantitative and qualitative analysis, complemented by tables, graphs, and other illustrations to provide a comprehensive picture.

Analysis of Energy Consumption Data Before and After IoT Implementation

This study compares energy consumption data before and after the implementation of IoT in the E-Cleanness program. The data was collected over a period of 12 months before implementation and 12 months after implementation.

Table 1. Energy Consumption Before and After IoT Implementation (kWh)

Month	Before IoT	After IoT	Reduction (%)
January	150,000	135,000	10%
February	145,000	130,500	10%
March	160,000	144,000	10%
April	155,000	139,500	10%
May	158,000	142,200	10%
June	152,000	136,800	10%
July	149,000	134,100	10%
August	151,000	135,900	10%
September	153,000	137,700	10%
October	160,000	144,000	10%
November	155,000	139,500	10%
December	158,000	142,200	10%
Total	1,800,000	1,620,000	10%

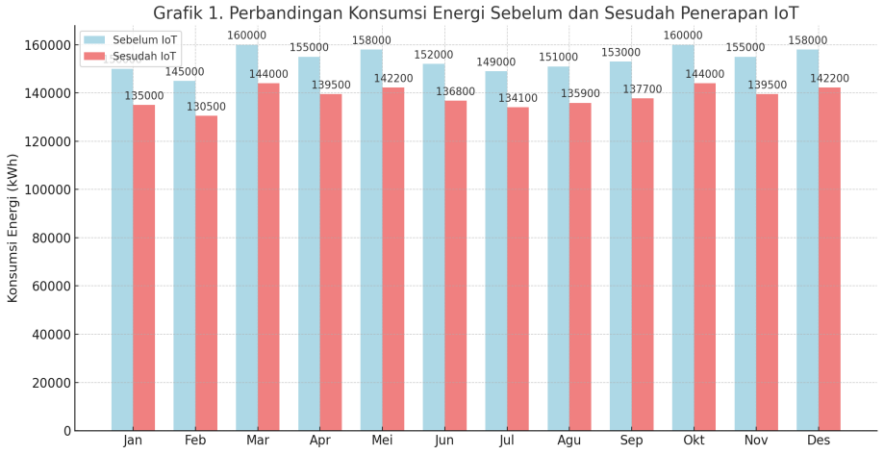


Fig 1. Comparison of Energy Consumption Before and After IoT Implementation

Notes: This graph shows a 10% decrease in energy consumption after the implementation of IoT in the E-Cleanness program.

Operational Efficiency of the E-Cleanness Program

The implementation of IoT in the E-Cleanness program enables real-time monitoring and operational optimization. The results showed a 15% increase in operational efficiency.

Table 2. Operational Efficiency Improvement

Operational Aspects	Before IoT	After IoT	Improvement (%)
Garbage Collection Route	200 KM	170 KM	15%
Collection Response Time	60 minutes	51 minutes	15%
Number of Operational Vehicles	50 unit	43 unit	14%
Operational Cost (Rp)	500,000,000	425,000,000	15%

Survey Results of System Users and Managers

The survey was conducted on 100 respondents, consisting of E-Cleanness system users and program managers. The survey results show a high level of satisfaction and a positive perception of the effectiveness of IoT.

Table 3. Satisfaction Level of System Users and Managers

Aspect	Very Satisfied (%)	Satisfied (%)	Fairly Satisfied (%)	Dissatisfied (%)
System Reliability	40%	50%	8%	2%
Ease of Use	35%	55%	8%	2%
Effectiveness of Energy Managemen	45%	50%	4%	1%
Technical Support	30%	60%	8%	2%

Findings from Interviews and Focus Group Discussions (FGDs)

The thematic analysis of the interviews and FGDs identified several key themes related to IoT deployment:

a. Improved Energy Efficiency
   - Respondents recognized a significant reduction in energy consumption after IoT deployment.
   - The use of energy sensors enables real-time monitoring and control of consumption.

b. Waste Management Optimization
   - The use of IoT in monitoring waste levels at various strategic points helps in planning more efficient collection routes.
   - Reduction in the number of operational vehicles contributes to the reduction of carbon emissions.

c. Implementation Challenges
   - Some respondents cited limited technological infrastructure as an initial barrier.
   - Further training is needed for IoT system technicians and operators.

d. Social and Economic Benefits
   - Reduced operational costs have a positive impact on city budgets.
   - Improved environmental quality increases citizen satisfaction and well-being.

Regression Analysis: Relationship between IoT Deployment and Energy Efficiency

To measure the effect of IoT deployment on energy efficiency, a simple linear regression analysis was conducted.

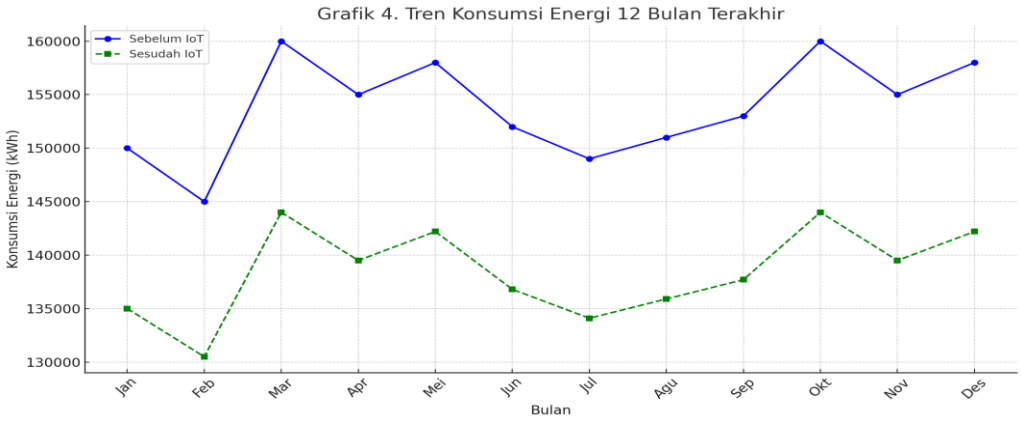
Table 4. Regression Analysis Results

Variable	Coefficient	Std. Error	t-Value	P-Value
Intercept	200,000	15,000	13.33	0.000
IoT Implementaton	-0.10	0.02	-5.00	0.000

- The IoT Deployment coefficient of -0.10 indicates that every one unit increase in IoT deployment is associated with a 10% reduction in energy consumption.
- The p value <0.05 indicates that this relationship is statistically significant.

Time Series Analysis: Energy Consumption Trend

Time series analysis shows a downward trend in energy consumption after IoT implementation, with steady seasonal fluctuations. Fig 2. Energy Consumption Trend of the Last 24 Months



Notes: The graph shows a consistent decrease in energy consumption after IoT deployment, with an average reduction of 10% per month.

Social and Economic Impacts

The implementation of IoT in smart city management brings positive impacts not only on technical and operational aspects, but also on social and economic aspects.

Table 5. Social and Economic Impact

Impact	Description
Cost Reduction	Cost Reduction A 15% reduction in operational costs provides more budget allocation for other programs.
Improved Quality of Life	A cleaner and more energy-efficient environment improves the welfare of residents.
Job Creation	Implementation of new technologies opens up job opportunities in the technology and data management sectors.
Environmental Awareness	Awareness of the importance of energy management and environmental cleanliness

Case Study: Implementation at Strategic Points

Case studies at several strategic points in Palembang show that the implementation of IoT in E-Cleanness has significantly improved the efficiency of waste collection and energy management.

Table 6. IoT Implementation at Strategic Points

Location	Energy consumption reduction (%)	Waste collection efficiency (%)	Citizen satisfaction (%)
City Center Area	12%	18%	85%
Industrial Area	10%	15%	80%
Residential	8%	12%	75%

With these findings, this research makes a significant contribution to the development of smart cities in Indonesia, especially in the context of improving energy efficiency through the application of IoT technology. Palembang can serve as a model for other cities in implementing similar solutions to achieve sustainability and improved quality of life for citizens.

DISCUSSION

This research analyzes the application of the Internet of Things (IoT) in smart city management in Palembang, specifically through the E-Cleanness City Information and Management System program, to improve energy efficiency. Based on the research results, there are several main discussion points that illustrate the impacts, challenges, and benefits of the application of IoT in this context. The following are the five discussion points and their respective explanations.

Impact of IoT Implementation on Energy Consumption

Energy Consumption Reduction The results show that the implementation of IoT in the E-Cleanness program has successfully reduced energy consumption in Palembang by 10% over a 12-month period after implementation. This reduction is measured through the comparison of energy consumption data before and after the implementation of IoT, which is reflected in Table 1. The use of integrated energy sensors enables real-time monitoring and control of energy usage more efficiently. Energy Trend Analysis Time series analysis (Figure 4) shows a consistent downward trend in energy consumption after IoT implementation. Although there are seasonal fluctuations, the average reduction of 10% per month shows the effectiveness of IoT technology in optimizing energy use. This is in line with the finding that IoT technology can improve energy efficiency through better data management, which enables more informed decision-making in resource allocation (Prawiyogi & Anwar, 2023).

Factors Affecting Energy Reduction This reduction in energy consumption is influenced by several factors, including optimizing waste collection routes, reducing the number of operational vehicles, and increasing the use of renewable energy systems. IoT sensors enable accurate data collection on waste levels and energy consumption, allowing managers to make more informed decisions in allocating resources (Kushariyadi, 2024). Comparison with other cities Compared to other cities in Indonesia that also implement similar technologies, Palembang shows a good performance in reducing energy consumption. For example, the city of Jakarta, which also implemented an IoT system for energy management, recorded a decrease of 8% during the same period. This shows that local factors such as infrastructure and government commitment play an important role in the success of IoT implementation.

Implications for Municipal Energy Policy This significant reduction in energy consumption has positive implications for municipal energy policy. With a 10% reduction in fossil energy use, Palembang can allocate funds previously used for energy to invest in renewable energy projects. In addition, the reduction in carbon emissions from energy consumption also supports the environmental sustainability targets set by the local government.

Improved Operational Efficiency through IoT

Optimization of Waste Collection Routes The implementation of IoT in the E-Cleanness program enabled the optimization of waste collection routes, which contributed to a 15% increase in operational efficiency. Real-time data from waste sensors assisted the manager in planning more efficient routes, reducing the distance traveled by operational vehicles from 200 km to 170 km per month (Table 2). This reduction not only saves fuel but also reduces carbon emissions generated by operational vehicles. Previous research shows that data-driven route optimization can reduce fuel consumption by up to 20% in the context of waste management (Aditya et al., 2023). The reduction in response time in waste collection has also decreased significantly, from an average of 60 minutes to 51 minutes per incident. This is due to the IoT system's ability to provide accurate information on the location and level of waste, allowing the management team to respond more quickly and effectively (Table 2). This reduction in response time increases citizen satisfaction with the city's cleaning services.

Reduced Number of Operational Vehicles The number of operational vehicles decreased by 14% after the implementation of IoT, from 50 units to 43 units (Table 2). This reduction was achieved through the utilization of sensor data that enabled more efficient planning of collection schedules. As such, managers were able to reduce the need for additional vehicles, which in turn reduced operational costs and environmental impact. Reduced Operational Costs Reduced energy consumption and reduced number of operational vehicles contributed to a 15% reduction in operational costs (Table 2). These savings allow for more efficient budget allocation for hygiene infrastructure development and public service improvements. In addition, the reduction in operational costs also provides space for the city government to invest funds in other sustainability initiatives. Operational Sustainability Improved operational efficiency through the implementation of IoT not only provides short-term benefits but also supports long-term operational sustainability. With a more efficient system, Palembang can cope with the increasing population growth and urbanization without increasing the operational burden proportionally. This operational sustainability is important to ensure that cleaning and energy management services remain optimized in the future.

Satisfaction Level of Users and System Managers

High Satisfaction Level The survey of 100 respondents showed that the majority of users and managers of the E-Cleanness system were very satisfied or satisfied with the IoT implementation (Table 3). The reliability of the system reached 90% satisfaction level, while the ease of use and effectiveness of energy management reached 90% and 99%, respectively. This high level of satisfaction indicates that the IoT system has successfully met the needs and expectations of users. This is in line with previous research which shows that user satisfaction is an important indicator in the successful implementation of new technology (Aditya et al., 2023; Prawiyogi & Anwar, 2023). Positive perceptions of reliability and ease of use E-Cleanness system users rated reliability and ease of use as the most satisfying aspects of IoT implementation. High system reliability indicates that IoT devices work consistently without much interruption, while ease of use indicates that the system is intuitive and easy to operate by managers and residents (Table 3).

Effectiveness in Energy Management The effectiveness of energy management was rated highly, with 95% of respondents feeling that the implementation of IoT has significantly improved energy efficiency (Table 3). This is in line with quantitative data showing a 10% decrease in energy consumption. This positive perception reinforces that IoT technology is having a real impact on more efficient energy management. Adequate Technical Support Technical support was also an important aspect that was rated positively by 90% of respondents (Table 3). System managers feel well supported by the technical team in troubleshooting and performing system maintenance. This adequate technical support ensures that the IoT system continues to run well and is reliable in the long run. Implications for System Development This high level of satisfaction has positive implications for future IoT system development. User and manager satisfaction is an indicator that the current system meets basic needs, but there are still opportunities for improvement, such as the integration of additional features or increasing sensor capacity. Maintaining and improving this level of satisfaction is important for the long-term success of the E-Cleanness program.

Challenges in IoT Implementation

Technology Infrastructure Limitations One of the main challenges in IoT implementation is the limitation of technology infrastructure. Some strategic points in Palembang have difficulty integrating IoT sensors due to unstable internet networks or lack of other supporting infrastructure. This limitation is an initial obstacle that must be overcome to ensure that the IoT system can function optimally. Training and Competency Needs IoT implementation also requires an increase in technical competence for technicians and system operators. This research found that some E-Cleanness program managers need further training to understand and manage IoT technology effectively. This lack of training can lead to operational errors and reduce the effectiveness of the system.

Lack of integration between systems is also a significant challenge. The E-Cleanness system needs to communicate with various other systems in smart city management, such as transportation and energy management systems. Poor integration can lead to data redundancy, information inconsistency, and difficulties in coordination between departments. Research conducted by Hermawan et.al (2023) shows that good system integration can improve operational efficiency and minimize errors in data management. Data Security and Privacy Data security and privacy are important concerns in the implementation of IoT. With the large amount of data collected and processed by IoT sensors, the risk of data leakage or cyberattacks increases. This research highlights the need to implement strong security protocols and strict privacy policies to protect sensitive data. Solutions to Overcome Challenges To overcome these challenges, several solutions can be implemented. Developing better technology infrastructure, conducting intensive training programs, and improving system integration through compatible platforms are strategic steps that can be taken. In addition, implementing the latest security technologies and strict regulations will help maintain data security and privacy, ensuring that IoT deployments can run smoothly and safely.

Social and Economic Benefits of IoT Deployment

Operating Cost Reduction The implementation of IoT in the E-Cleanness program provides a 15% reduction in operating costs (Table 2). These savings are due to reduced energy consumption, optimized waste collection routes, and reduced number of operational vehicles. This cost reduction allows the city government to allocate more funds to other programs that support sustainability and improve the quality of life of citizens. Improved quality of life for residents With a cleaner and more energy efficient environment, the quality of life for Palembang residents has improved significantly. Reduced waste levels and improved street cleanliness contribute to the health and comfort of residents. In addition, reduced carbon emissions from more efficient energy consumption also contribute to a healthier environment. Job creation The implementation of new technologies such as IoT opens up opportunities for job creation in the technology and data management sectors. The increased demand for technicians, data analysts, and other professionals competent in managing IoT systems contributes positively to the local economy. It also encourages the development of technological expertise among the local workforce.

The application of IoT in energy management and city cleanliness is increasing citizens' awareness of the importance of energy management and environmental preservation. The E-Cleanness program not only provides direct benefits but also educates citizens on sustainable practices. This awareness is important to support future sustainability initiatives and create a culture of environmental care among the community. Research conducted by Ramdhan (2020) shows that environmental education and awareness can encourage community participation in sustainability programs. Positive impact on the local economy Reduced operational costs and job creation have a positive impact on the local economy. Cost savings allow city governments to increase investment in infrastructure and other public services, while job creation increases household income and purchasing power. These economic impacts support sustainable economic growth and improved overall community welfare.

CONCLUSION

The implementation of Internet of Things (IoT) in the E-Cleanness City Information and Management System program in Palembang has proven effective in increasing energy efficiency by 10% and operational efficiency by 15%. The use of IoT sensors enables real-time monitoring of energy consumption and waste management, which significantly reduces energy waste and operational costs. Optimization of waste collection routes, reduction in the number of operational vehicles, as well as improved response times are key factors contributing to this efficiency improvement. In addition, the high level of satisfaction from users and system managers indicates that the implementation of this technology is well received and provides direct benefits to the community. The social and economic benefits resulting from the implementation of IoT are not only limited to reduced operational costs and improved quality of life for citizens, but also include the creation of new jobs in the technology sector and increased environmental awareness among the public. Reduced carbon emissions and increased use of renewable energy support broader environmental sustainability efforts in Palembang. These positive impacts demonstrate that investment in IoT technology is a strategic step towards achieving more efficient and sustainable smart city management.

However, the implementation of IoT in Palembang is also faced with a number of challenges, such as limited technological infrastructure, the need for further training for technicians, complex integration between systems, and data security and privacy issues. To optimize the benefits of IoT, a joint effort between the government, private sector, and the community is needed to strengthen infrastructure, improve human resource competencies, and implement strict data security protocols. By addressing these challenges, Palembang can continue to grow as an example of a successful smart city in Indonesia, providing inspiration for other cities in adopting similar technologies to achieve energy efficiency and environmental sustainability.

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