GREEN COMPUTING AND IOT: TOWARDS A SUSTAINABLE FUTURE FOR SMART DEVICES

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Abstract: The rapid development of smart devices and the Internet of Things (IoT) has opened up huge opportunities in various sectors, including smart homes, industry and transportation. However, the surge in use of IoT devices also poses serious challenges in terms of energy consumption, e-waste and environmental impact. This research explores the concept of green computing in the context of IoT as an effort to create a more sustainable future. By adopting green computing principles, such as energy efficiency, use of renewable resources, and environmentally friendly device design, this research aims to identify strategies that can be implemented to reduce the carbon footprint of smart devices. In addition, this study examines various technologies that support energy savings in IoT systems, such as more efficient power management algorithms, low-power sensor technologies, and the use of energy-efficient cloud computing. The results of this research are expected to provide insight for device developers and policy makers about the importance of integrating green solutions in the life cycle of IoT devices, from design to disposal. Thus, the application of green computing in IoT has the potential to support the global sustainability agenda while ensuring optimal performance of smart devices in the future.

INTRODUCTION

In today's digital era, the use of information and communication technology (ICT) is increasing, along with the rapid growth of the Internet of Things (IoT). Smart devices connected to the internet network facilitate various aspects of human life, from energy management, health, to transportation. However, this rapid growth has a negative impact on the environment, especially in terms of energy consumption and carbon emissions. Along with the development of IoT, the integration of green computing principles is becoming increasingly important to ensure that technological growth is not only economically beneficial but also ecologically sustainable. Gubbi et al. (2013) emphasized the need for strategies that combine energy efficiency with technological innovation to create greener solutions. Although the concept of green computing has

been introduced and applied in several contexts, there are still many challenges that need to be overcome. Among them is the lack of understanding and application of green computing practices in the development and management of IoT devices. In addition, the measurement of the environmental impact of smart devices and the development of standards for sustainability evaluation are still limited. This results in low adoption of environmentally friendly technologies among developers and users. This study aims to explore the relationship between green computing and IoT and evaluate the potential for implementing green computing practices in the development of IoT devices. This study also aims to identify the challenges and opportunities faced in implementing green strategies in the technology industry. By understanding these dynamics, it is hoped that this study can contribute to the development of more sustainable and environmentally friendly technology solutions in the future.

Green computing is a concept that refers to the use of energy-efficient and environmentally friendly information technology. According to Murugesan (2008), green computing is "the practice of designing, producing, using, and disposing of computers, servers, and related devices in an efficient and effective manner while taking into account environmental impacts." Murugesan highlights that green computing is not just about saving energy on devices during their operation, but also encompasses the entire life cycle of the device, from design, production, operation, to recycling. Zhang et al. (2021) expand the concept of green computing by adding that optimizing power consumption, especially in distributed systems such as IoT, is key to achieving sustainability. They identify energy management, carbon footprint reduction, and resource optimization as key pillars of green computing in the context of smart devices and interconnected networks. Energy Efficiency in IoT The Internet of Things (IoT) involves a network of interconnected smart devices to collect, share, and analyze data. Despite its great benefits in various sectors, the high energy consumption of IoT devices has become a major concern. Kumar et al. (2020), energy efficiency in IoT is crucial because most IoT devices operate wirelessly and rely on batteries. Therefore, the development of energy-efficient technologies and low-power sensors is essential. Kumar also emphasized the importance of using energy harvesting technologies, where IoT devices can utilize external energy sources such as solar or thermal energy to extend their operational life without having to frequently replace or recharge batteries. Li et al.

(2021) identified that power management algorithms also play an important role in reducing the energy consumption of IoT devices. They suggested the use of algorithms that allow smart devices to switch between active and sleep modes as needed, to save energy without compromising device performance. Sustainability has become a central topic in discussions about modern technology. Moreno et al. (2021) highlighted that the exponential growth of IoT is increasing the production of electronic waste (e-waste), which is a significant environmental problem. They proposed that IoT devices should be designed with recycling and life extension in mind, to reduce their negative impact on the environment. Green Computing in the Context of IoT The integration of green computing in IoT emphasizes the importance of more efficient resource management to achieve long-term sustainability. Wang et al. (2021) argued that by leveraging cloud computing, which allows computing to be performed in data centers optimized for energy efficiency, IoT devices can reduce their power consumption. Shifting heavy processing from IoT devices to energy-efficient cloud data centers helps reduce the power load on individual devices and maximizes efficiency.

In addition, Ahmed et al. (2022) highlighted the important role of green technology in driving energy efficiency and sustainability in IoT. They proposed the use of environmentally friendly materials for the production of IoT devices and the application of renewable energy technologies such as solar panels to support the operation of these devices. This is in line with the global trend that increasingly emphasizes the importance of reducing the carbon footprint and the transition to a low-emission economy. The design of environmentally friendly smart devices is one of the important principles in green computing. Plepys (2002) emphasized that the concept of eco-design should be applied to the development of electronic devices, including IoT, to reduce environmental impacts throughout the life cycle of the device. This includes the use of recyclable materials, reducing the use of hazardous materials, and increasing the energy efficiency of devices from the design phase. Zhao et al. (2022) also highlighted the importance of recycling and e-waste management in the development of IoT devices. They noted that technology companies must commit to creating an ecosystem where electronic devices can be recycled effectively, and e-waste can be better managed to reduce environmental damage.

RESEARCH METHODS

This study uses a quantitative method with a survey approach to collect data. This method was chosen because it allows statistical analysis of variables that influence the application of green computing principles in the context of IoT. According to Zhang et al. (2021), the use of quantitative methods in green computing studies provides a clearer picture of the relationship between technology and environmental impacts.

1. **Population and Sample**

   The population in this study are IoT device developers, end users, and technology companies involved in the development and implementation of IoT solutions. Gubbi et al. (2013) stated that it is important to involve various stakeholders in the study to obtain a comprehensive view. The sampling technique used is stratified sampling, where the population is divided into strata based on certain criteria such as industry, company size, and experience in using IoT devices. A minimum of 150 respondents will be expected to ensure representative data.

2. **Research Instruments**

   The instrument used in this study is a questionnaire consisting of several parts, including:

   a. Respondent Demographics: Data on age, gender, education, and professional background.
   b. Knowledge and Attitudes towards Green Computing: Using a Likert scale to measure respondents' knowledge and attitudes towards green computing practices.
   c. Use of IoT Devices: Questions about the types of devices used, frequency of use, and awareness of the environmental impact of the devices.
   d. Challenges in Implementation: Identifying obstacles faced in implementing green computing practices in the development and use of IoT devices.

According to Li et al. (2021), a well-designed questionnaire can increase the validity and reliability of the data collected.

1. Data Collection Procedure

   Data collection is conducted online using a survey platform that allows for efficient

data collection. The questionnaire will be distributed via email, social media, and technology-related forums. Prior to distribution, a pilot test of the questionnaire will be conducted to ensure the clarity and accuracy of the questions.

2. Data Analysis

   The collected data will be analyzed using statistical software such as SPSS. The analysis to be carried out includes:

   a. Descriptive Statistics: To describe the demographic characteristics and usage patterns of IoT devices.
   b. Correlation Analysis: To evaluate the relationship between knowledge of green computing and practices applied in the use of IoT devices, in accordance with the findings by Zhao et al. (2022).
   c. Multiple Regression: To determine the factors that influence the level of adoption of green computing practices among developers and users of IoT devices.

RESULTS AND DISCUSSION

Research Results :

1. Respondents: of the total 150 respondents who participated in this study, the majority were IoT device developers (60%), followed by end users (30%) and technology companies (10%). In terms of demographics, respondents consisted of 55% men and 45% women, with the largest age range being between 25-34 years (40%). The average work experience in the technology field was 5 years.
2. Knowledge of Green Computing: the results of the analysis showed that 70% of respondents had good knowledge of the principles of green computing. Around 65% of respondents stated that they were aware of the environmental impact of the IoT devices they use. This knowledge is in line with the findings of Li et al. (2021) which showed that understanding green computing can increase awareness of environmentally friendly practices.
3. Implementation of Green Computing Practices: of the 150 respondents, 55% stated that they actively implement green computing practices in the development or use of IoT devices. The most commonly adopted practices include the use of renewable energy (40%), energy efficiency (35%), and e-waste management (25%). This shows that

despite awareness, the implementation of these practices still needs further encouragement.

4. Challenges in Implementation: respondents also faced various challenges in implementing green computing practices, with 60% stating that high costs were the main factor. In addition, the lack of clear regulations and standards (45%) and lack of understanding of best practices (30%) were also obstacles. This finding is in line with the statement by Gubbi et al. (2013) who emphasized the need for supportive policies to facilitate the adoption of green computing.
5. Correlation Analysis: correlation analysis showed a significant positive relationship between knowledge of green computing and the level of implementation of environmentally friendly practices in the use of IoT devices ($r = 0.67$, $p < 0.01$). This emphasizes the importance of education and training in increasing the adoption of green computing practices among users and developers.

Discussion

The results of this study indicate that although awareness and knowledge of green computing among IoT device developers and users is quite high, the challenges faced in implementing environmentally friendly practices are still significant. This is in line with the findings of Zhao et al. (2022), who stated that despite advances in green technology, wider adoption requires more effective strategies to overcome existing barriers. The adoption of renewable energy and energy efficiency shows that positive steps are being taken, but this wider adoption needs to be supported by stronger policies and clear regulations.

1. Percentage Formula

Percentage is used to measure the proportion of respondents who have knowledge or implement a particular practice.

$$\text{Percentage} = \frac{Jumlah\ Responden\ dengan\ karekterisitik\ tertentu}{Total\ Responden} \times 100$$

If 105 out of 150 respondents stated that they know about green computing, then:

Percentage of Knowledge: $\frac{\mathbf{105}}{\mathbf{150}} \times 100 = 70\%$

2. Mean

The mean is used to obtain the middle value of numerical data, such as the level of implementation of green computing practices.

Average = $\frac{\Sigma X}{N}$

where : $\boldsymbol{X}$ = observed value $\boldsymbol{N}$ = number of observations

If the level of implementation of green computing practices by 5 respondents is 3, 4, 2, 5, and 4, then the average is:

Average = $\frac{\mathbf{3+4+2+5+4}}{\mathbf{5}} = \frac{\mathbf{18}}{\mathbf{5}} = 3.6$

3. Pearson Correlation

Used to measure the strength and direction of a linear relationship between two variables, such as knowledge of green computing and the level of implementation of the practice.

$$r = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[n\Sigma X^2 - (\Sigma X)^2]\ [n\Sigma Y^2 - (\Sigma Y)2]}}$$

where : $\boldsymbol{n}$ = amount of data, $\boldsymbol{X\ dan\ Y}$= two variables analyzed

4. Simple Linear Regression Formula

Used to predict the value of a dependent variable based on the independent variable.

$$\boldsymbol{y = a + b\chi}$$

Where =

$\boldsymbol{y}$ = dependent variable

$\boldsymbol{a}$ = intercept

$\boldsymbol{b}$ = regression coefficient

$\boldsymbol{\chi}$ = independent variable

5. Validity and Reliability Test

To measure the validity of the questionnaire, the Construct Validity formula (factor analysis) can be used and for reliability, the following can be used:

Cronbach's =

$$\boldsymbol{\alpha = \frac{k}{k-1}\left(1 - \frac{\Sigma s_i^2}{s_t^2}\right)}$$

Where =

$\boldsymbol{k}$ = number of items in the questionnaire

s_i^2 = Item variance

s_t^2 = total variance

CONCLUSION

This study aims to explore the relationship between green computing and the application of IoT technology and to identify the challenges and opportunities in creating more sustainable solutions. Based on the analysis of data obtained from 150 respondents, a number of conclusions can be drawn:

1. High level of knowledge: most respondents have a good understanding of the principles of green computing. Around 70% of respondents indicated awareness of the environmental impacts of using IoT devices, indicating potential for wider adoption of green practices.
2. Adoption of green practices: despite high awareness of the importance of green computing, only 55% of respondents actively adopt such practices in the development and use of IoT devices. This indicates a gap between knowledge and action that needs to be addressed.
3. Challenges faced: this study identified several key challenges in the adoption of green computing, including high costs, lack of clear regulations, and limited knowledge of best practices. This is in line with previous studies that emphasize the need for policy support to overcome these barriers.
4. Significant positive relationship: the results of the analysis show a significant positive relationship between knowledge of green computing and the level of adoption of green practices ($r = 0.67$, $p < 0.01$). This confirms the importance of education and training in increasing the adoption of green technologies.
5. Recommendations for policy development: to encourage the adoption of green computing in IoT technology, supportive policies and incentives are needed for developers and users of devices. Collaboration between stakeholders, including government, industry, and academia, is essential to create a sustainable ecosystem.

Overall, this study shows that the integration of green computing in the development of IoT devices can help achieve a more sustainable future. Therefore, collective action

is needed to reduce the environmental impact of technology and promote the use of more environmentally friendly solutions. This study provides valuable insights for stakeholders in developing effective strategies and policies to facilitate the implementation of green computing in this evolving digital era.

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