

Smart Energy Management for Sustainability: An Exploration of the Potential of IoT and AI Technologies

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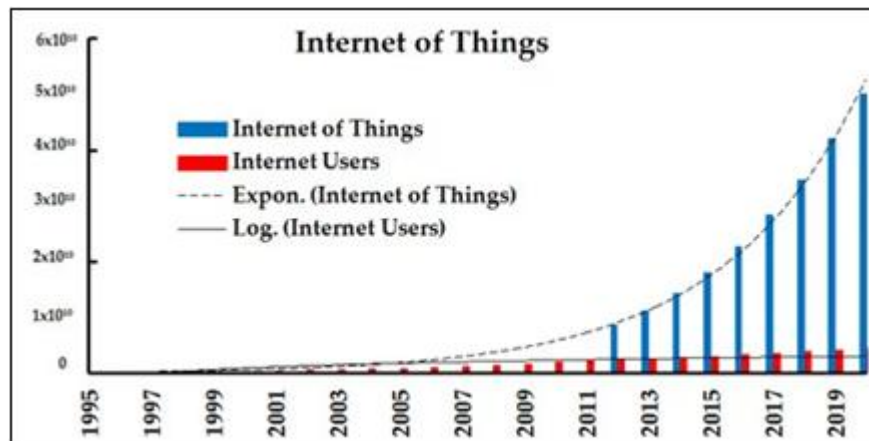
Abstract: IoT is a topic that comes up these days whenever one is discussing sustainability and smart cities. But what role does IoT play in improving sustainability and building smart cities? "Internet of Things" (IoT) describes a network in which devices like cars and household appliances are networked with one another. This allows data to be exchanged for improved automation and efficiency in day-to-day activities. The possible effects of the Internet of Things (IoT) on sustainability are examined in this study. Three groups—students, IoT professionals, and sustainability specialists—took part in a survey to collect their opinions regarding the use of IoT to promote sustainability. A considerable proportion of respondents stated that they believe IoT might make a meaningful contribution to sustainability if it is used to its fullest extent. The study also uses secondary sources to give a thorough picture of IoT's potential. Remarkably, the study revealed restrictions that went against the common belief regarding IoT, illuminating important difficulties that arise when IoT is used in the context of smart city and sustainability projects.

Keywords: IoT, sustainability, smart cities, automation, efficiency

1. Introduction

The Internet of Things (IoT) is viewed as the next stage in the development of the Internet (mdpi.com). It is a networked system of physical objects with different processing, sensing, and actuation capabilities that can collaborate and communicate using the Internet as a

common platform (Pourbeik, 2021). IoT utilizes smart devices and the internet to provide innovative solutions to a variety of issues and challenges affecting numerous industries, including business, healthcare, etc (A Review - Journal of Big Data 2019). Since 2011 there has been an exponential growth in the use of IoT. This is clearly seen in the graph (mdpi.com):



How IoT can help with sustainability

- **IoT to reduce vehicle emissions**

IoT - powered sensors can monitor a variety of variables to improve vehicle performance or analyze data to recommend more intelligent, eco - friendly methods to operate various vehicles. IoT - enabled traffic management systems can, on a broad scale, lessen traffic congestion, which will reduce emissions from idling automobiles. Consumer - level IoT sensors can keep an eye on a car's state and foretell when a repair is necessary, which can lower emissions by ensuring that the car is operating as efficiently as possible (Team, 10 benefits of IOT Energy Management Systems 2023). IoT sensors may also track and improve the performance of a fleet of vehicles in the industrial setting, encouraging more

fuel - efficient driving and cutting emissions (IOT for sustainability - can IOT lead to a greener planet? 2018).

- **Air Pollution Monitoring**

A new generation of air quality monitoring that gives reliable data at a fraction of the expense of older monitoring systems has been made possible by recent innovations in low - cost pollution sensors. For instance, the main gas found in natural gas, methane, is a strong greenhouse gas that accounts for 20% of global emissions. The oil and gas sector, which emits \$30 billion worth of methane annually from operations, is the main industrial emitter. In this situation, a low - power wide area network (LPWAN) - enabled air quality monitoring technology can give operators real - time insight into previously undetectable leaks in

distant, remote areas and the capability to remotely manage valves to stop additional methane leakage (Prasad, IOT in energy management - use cases, benefits, & future trends 2023).

- **IoT to reduce food waste**

Food waste has a larger carbon footprint than the airline industry, making it a significant contribution to climate change. The World Wildlife Fund (WWF) predicts that more than a third of food produced worldwide is wasted. That equates to 4 trillion tonnes of water wasted in the United States. And that doesn't even take into account the energy required for its harvest, transportation, and packaging. We could cut the overall amount of greenhouse gas emissions brought on by people by up to 8% if we stopped wasting food. Food waste and deterioration are primarily caused by insufficient temperature. Produce loses its freshness when left out in the open or in a crate in unfavorable weather after harvest. Produce's shelf life is shortened the more time it spends in temperatures that are either too hot or too low. IoT sensors can detect and change temperatures by remotely monitoring harvested produce. According to the World Economic Forum, this tracking can cut food waste by 40% (ntarShaddad H. Abdul - Qawy 1, 1, 2, & Abstract). The past few years have witnessed a rapid growth of IoT - based wireless systems in different sectors (The IoT heterogeneous devices, 2020).

- **Smart Energy Management**

While user comfort and cost - effectiveness have always been top priorities in the design of HVAC and lighting systems, customers and communities are increasingly emphasizing sustainable technologies. More than 40% of the energy used by a business building is used for energy consumption. It makes sense that so many facility managers (FMs) are looking for ways to maximize the effectiveness of this system. Up until recently, the regulation of HVAC systems was frequently uniform and predetermined, which resulted in wasteful issues like overheating or underheating throughout the building. In this situation, on - demand, micro - zoned equipment control is made possible by real - time, granular IoT sensor data to increase energy efficiency. Additionally, utilizing occupancy data can reveal significant trends in HVAC and lighting requirements, allowing for the optimization of equipment schedules. Facility managers can significantly reduce their carbon footprint by cutting daily energy use by one hour, for instance, if HVAC and lighting systems are programmed to run until 8 pm but data shows tenants don't stay past 7 pm. Wireless utility submeters assist in delivering consumption data at distinct building areas or even on individual assets, particularly energy - intensive ones when it comes to usage monitoring. With these insights at their disposal, facility operators may quickly find bottlenecks and identify them for preventative measures (Mr. Edward, IOT Saving Energy 2017).

- **IoT for less light pollution**

The natural cycles of species are disrupted, ecosystems are disturbed, and energy is wasted as a result of light pollution. According to the International Dark - Sky Association, 30% of outdoor lighting in the United States is wasted, resulting in annual carbon dioxide emissions of 21 million tonnes. IoT technology can support the monitoring of lighting systems to

lessen the effects of light pollution on the environment and public health. We can program smart lighting systems to emit the necessary quantity of light and turn it off automatically when not required using IoT sensors. These sensors can determine when there is enough natural light, eliminating the need for artificial illumination. IoT devices have the ability to control brightness, making sure it stays within reasonable bounds. We can use data from IoT sensors to analyze lighting system performance and waste reduction.

- **IoT in Smart Cities**

IoT is converting the conventional civil framework of society into a high - tech structure with the concept of smart cities, smart homes, and smart cars and transportation. In order to comprehend the demand for and use of technology at home, rapid advancements are being made with the aid of supporting technologies like machine learning and natural language processing (Journal of Big Data (Internet of Things - Open Access Research 2016). For example: In order to avoid accidents and conserve energy, the IoT can be applied in this field to remote control devices that can be used to turn appliances on and off remotely. Refrigerators with LCD screens are among the smart household appliances, allowing you to see what is inside, what has been overstocked and is ready to expire, etc. You can obtain this information outside the home by connecting it to a smartphone. Additionally, you can network a range of kitchen appliances with a smartphone so that you can control the temperature, such as for an oven. The Internet of Things (IoT) can be utilized for home security via alarm systems and cameras that can be installed to watch and detect window or door openings to deter burglars. All these uses of IoT will allow the devices to be switched off when not in use and will avoid the wastage of electricity. This is not only environmentally friendly but also cost - friendly (IOT for sustainability - can IOT lead to a greener planet? 2018). Transform Insights found out that by 2030, businesses using IoT for energy "will save more than eight times the energy they consume." To put this amount into perspective, it is equal to 230 billion cubic meters of water or one gigaton of carbon dioxide emissions (Smart Energy Solutions 2016).

- **IoT Design Challenges**

- **Availability:** The capacity of an IoT system to deliver demanding services for consumers anytime and anyplace is referred to as availability.
- **Reliability:** Each IoT system needs to be dependable. It implies that the system must successfully supply IoT services under various conditions. In the world of applications for emergency response, this characteristic is more crucial. A communication network that is resilient to failures should be used by an effective IoT system. All of the IoT levels receive the information successfully from a dependable network. Long delays and data loss brought on by an unreliable network ultimately result in poor decisions. In an IoT system, poor judgments might result in unanticipated events like confusion, disorder, and irreparable harm (GeeksforGeeks, 2023).
- **Absence of encryption -** The absence of encryption is one of the biggest threats to IoT security, despite the fact that it is a terrific tool to stop hackers from accessing data. These drives are accustomed to the processing and storage power offered by a conventional computer. The

end outcome is an increase in attacks where hackers may quickly change the security algorithms.

- **Lack of testing and upgrading** - As the number of Internet of Things (IoT) devices grows, IoT manufacturers are more eager to develop and deploy their devices as quickly as possible without giving security too much thought. The majority of these IoT products and gadgets do not receive enough testing or updates, making them vulnerable to hackers and other security risks (IoT Design Space Challenges: Circuits and Systems, 2014).

2. Methodology

Research Design: A well - structured survey was conducted to gather valuable insights from three distinct groups: students, professionals working in the field of IoT, and Energy Management practitioners. The survey aimed to understand their views, awareness, and challenges related to integrating IoT into sustainable energy practices. The questionnaire included a mix of closed - ended and open - ended questions, focusing on key areas like awareness of IoT applications in energy management, perceived benefits, challenges, and future implications.

Sampling Strategy: Snowball Sampling was used to collect the samples. It began by purposefully selecting participants with expertise in IoT and energy management. Subsequent participants were added through a snowball sampling method, where existing participants referred colleagues or acquaintances who met the criteria. The inclusion criteria covered students interested in IoT and energy, as well as professionals working in the IoT sector and Energy Management.

Data Collection: To ensure ease of participation, the survey was conducted online. This mode eased the process of collecting responses from a diverse group of people, considering their different locations and professional backgrounds. To encourage more responses, persuasive techniques were used such as clear communication of the research goals, and assurance of confidentiality.

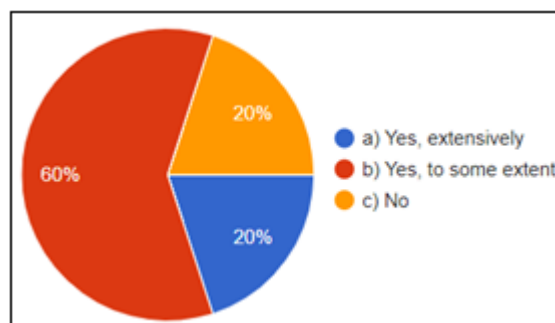
Secondary Data Collection: A thorough review of existing research, academic publications, and industry reports related to IoT applications in sustainable energy was undertaken. This secondary data provided a solid foundation for the research and helped contextualize the findings from the survey. Electronic databases, academic journals, and reputable industry sources were systematically searched to gather relevant articles and reports.

Data Analysis: Survey responses underwent both quantitative and qualitative analysis. Quantitative analysis, using statistical tools, helped identify patterns and correlations. Qualitative analysis involved looking at open - ended survey responses and insights from secondary sources. Thematic analysis was conducted to draw qualitative insights and gain a contextual understanding.

3. Results

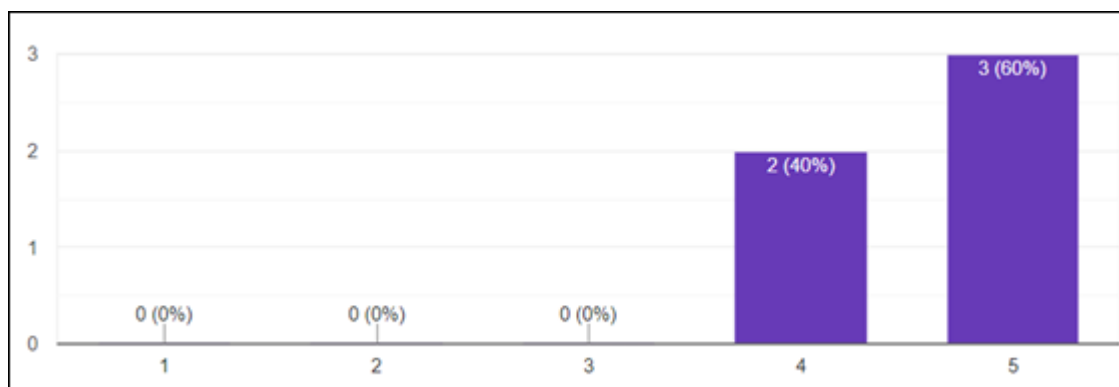
Analysis of Responses of Professionals Working in the Field of Sustainability and Energy Conservation

1) Implementation of IOT for Improving Energy Efficiency in the Field



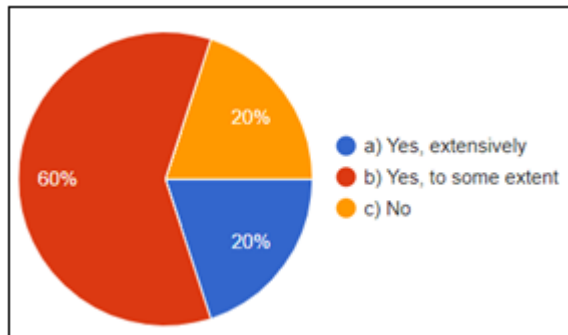
3 out of the 5 responses indicate that they have used some IoT devices to improve energy efficiency in their field and 1 said that they have used IoT extensively to improve energy efficiency. Moreover, only 1 person said that they have not used IoT for energy efficiency.

2) The potential of IoT in the field of energy efficiency



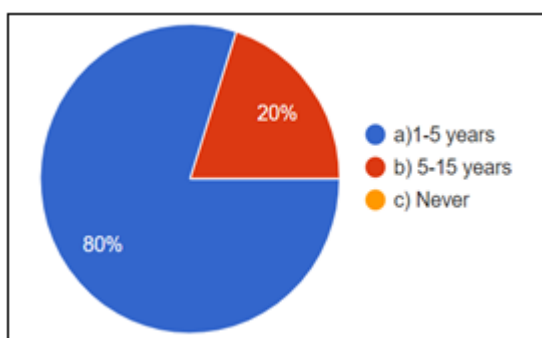
100% of the participants think that IoT has a lot of potential in the field of energy efficiency. 40% of participants think it has a potential of 4 on a 1 to 5 scale and 60% think that it has a potential of 5 on a 1 to 5 scale.

3) Use of IOT devices to optimize energy consumption in teh professional setting



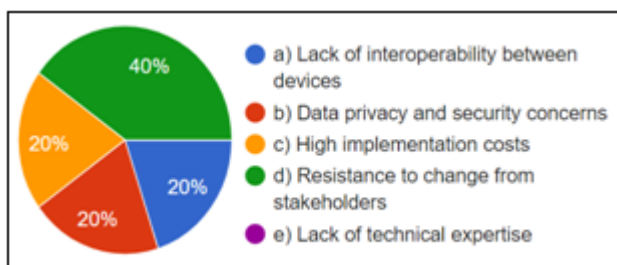
3 in 5 people have used IoT devices to some extent to monitor and optimize energy consumption, 1 in 5 has used IoT extensively and only 1 has never used IoT in the context mentioned above.

4) Anticipated timeline for common utilization of IoT for energy efficiency



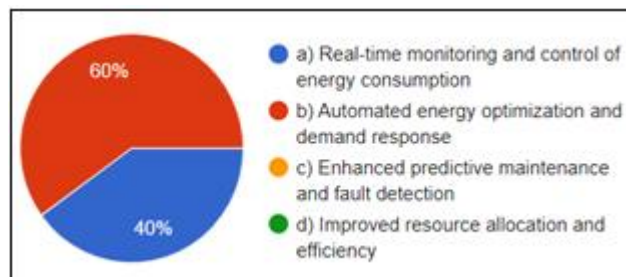
80% of the professionals think that IoT will be used efficiently within 1 - 5 years and 20% think that IoT will be used for energy efficiency in 5 - 15 years. It is also important to note that not even 1 person thinks that IoT will never be used for energy efficiency.

5) Expected challenges or barriers in the worldwide adoption of IOT for energy efficiency



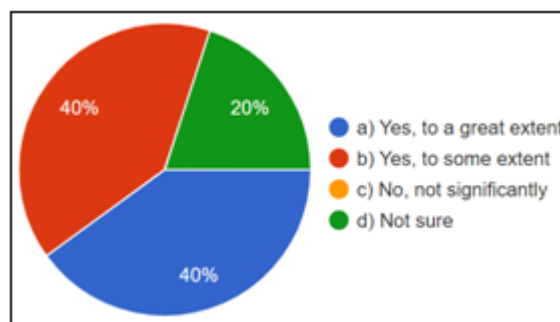
It is clear that 40% of the professionals think that there will be resistance to change from stakeholders and 1 person thinks that there would be a high implementation cost, similarly, 1 person also says that there are data and privacy concerns and 1 person also said that there might be a lack of interoperability between devices

6) Key benefits of utilizing IOT for energy efficiency



60% of professionals think that the key benefit of IoT is automated energy optimizations and demand response. Furthermore, 40% of the people think that real - time monitoring and control of energy consumption is the key benefit. It is important to note that no one thought that enhanced detective maintenance and fault detention and improved resource allocation and efficiency were the key benefits.

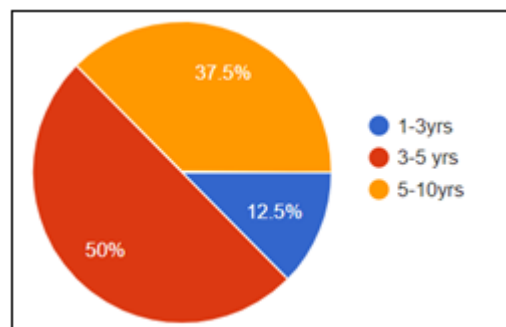
7) Use of IOT to drive behavior change among professionals to promote energy - efficient practices



80% of the people believe that IoT can effectively drive behavior changes among professionals and the other 20% were not sure.

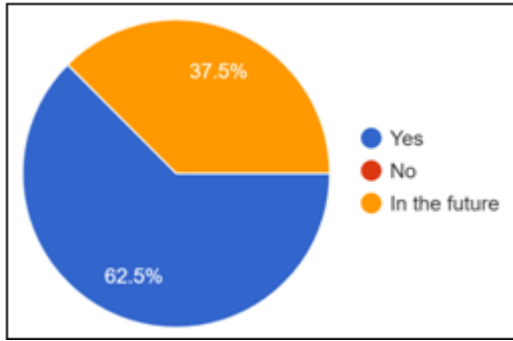
Analysis of responses of Professionals working in the field of IOT

1) Expected timeframe for when the Internet of Things (IoT) will become a prevalent household item



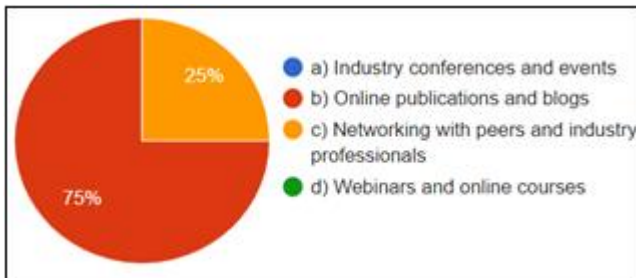
4 professionals out of 8 think that within 3 - 5 years IoT will become a household item. 1 person believes IoT would become a household item in 1 - 3 years and 3 people thought it would take 5 - 10 years.

2) Use of IoT for energy efficiency



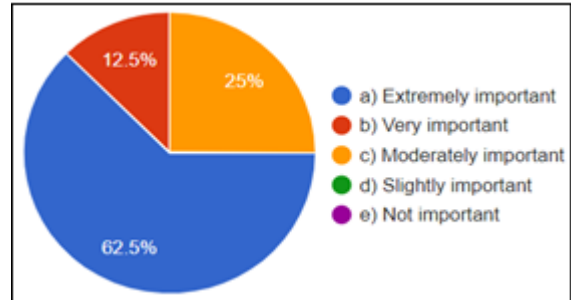
62.5% of the professionals believe that IoT can presently be used for energy efficiency. 37.5% of people think IoT can be used for energy efficiency but only in the future. It is also important to take note that not 1 person said IoT cannot be used for energy efficiency.

3) Ways to stay updated with the latest developments and trends in the IoT



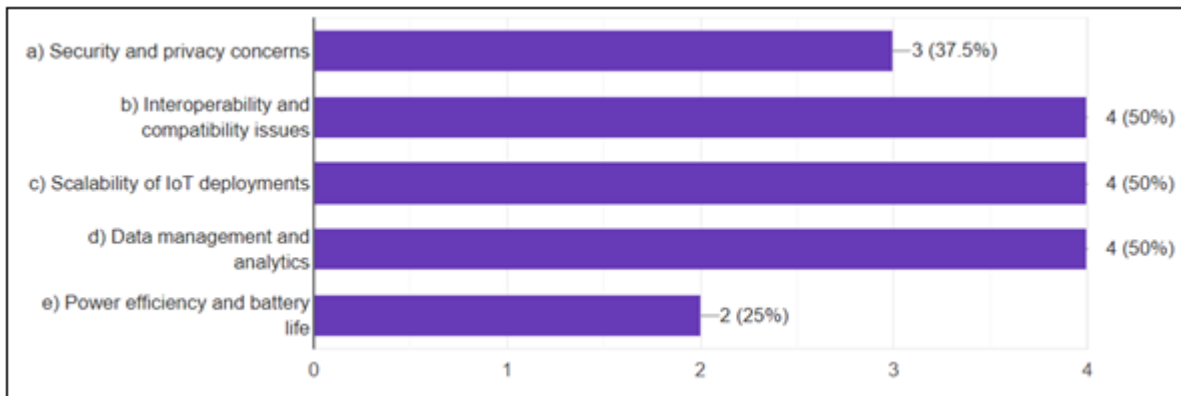
75% of people stay updated with the latest updates about IoT through online publications and blogs. The other 25% learn about it through networking with peers and industry professionals. Surprisingly not 1 professional learns about IoT through webinars online courses, industry conferences, and events.

4) Importance of data security in IOT solutions



Majority of the people think that data security is extremely important while developing IoT solutions. 12.5% of the people thought it was very important and 25% of the people thought it was moderately important. Not surprisingly not 1 person thinks that data security is slightly important or not important.

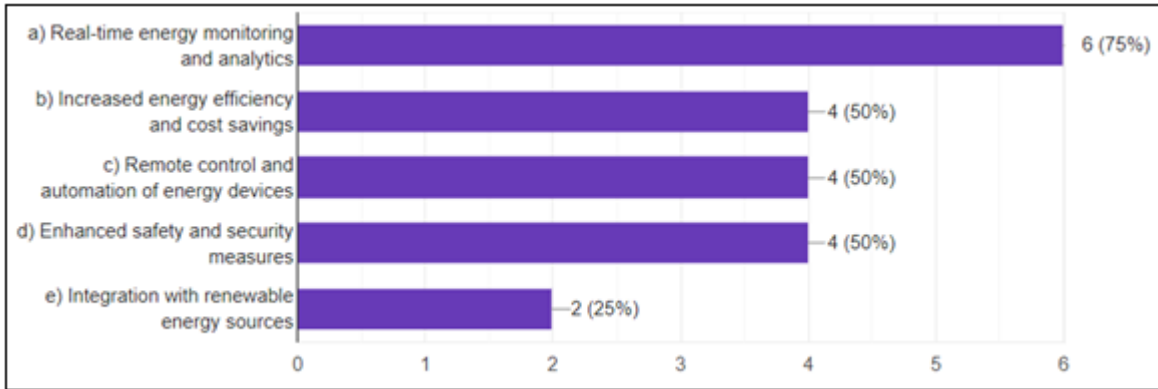
5) Primary challenges faced in developing IOT solutions



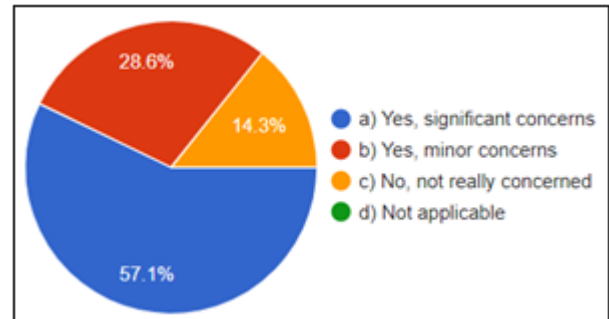
4 people think that interoperability and compatibility issues, scalability and IoT deployments, Data management, and analytics are the major problems that will be faced by IoT. 3 people thought that security and privacy concerns are a major problem IoT will face. Only 2 people thought that

power efficiency and battery life would be a problem for IoT solutions.

6) Most appealing benefits of IOT - based energy management systems in Singapore



75% of the people thought that Real - time energy monitoring and analytics are the most appealing benefits of an IoT - based energy management system.50% of the people thought that increased energy efficiency and cost saving, remote control and automation of energy devices, and enhanced safety and security measures are the best benefits that Singapore is getting from the development of IoT. Surprisingly only people thought that the integration with renewable energy sources was one of the most important benefits gained by Singapore.

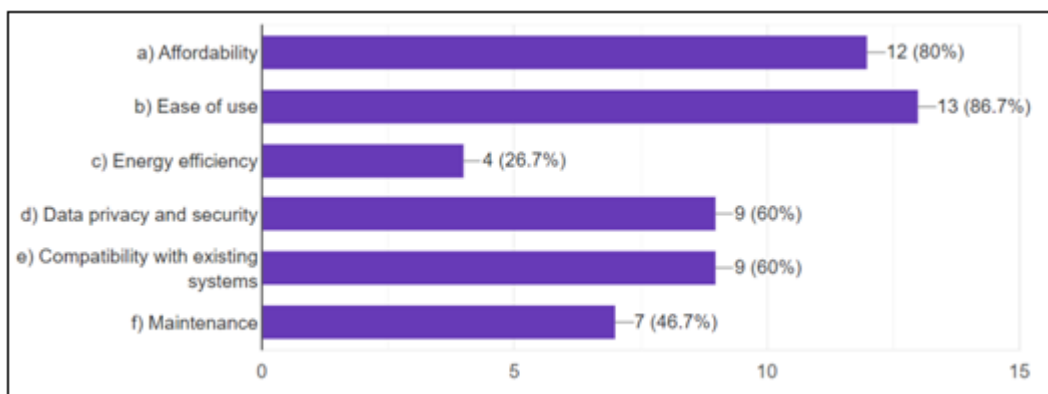


7) Security or privacy concerns associated with using IOT devices for energy efficiency

57.1% of the professionals thought that there are significant privacy or security concerns if we use IoT devices for energy efficiency.28.6% of the people think that there are concerns but only minor ones.14.3% think that the concerts are not that important and will not play an important role.

Analysis of responses of students regarding the use of IOT in their daily life

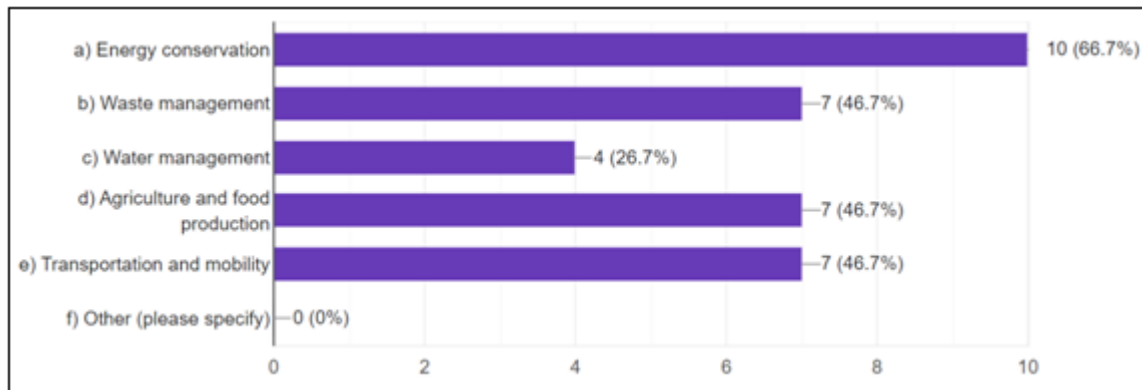
1) Considerations of factors while selecting/buying an IoT device or solution for sustainability



According to 86.7% of the students in the survey said that the main factor they considered while buying an IoT device is ease of use. This may be because many people are not comfortable with the latest technology and using it is not

always simple. If the IoT device is user - friendly and easy to use it may influence people to purchase it.

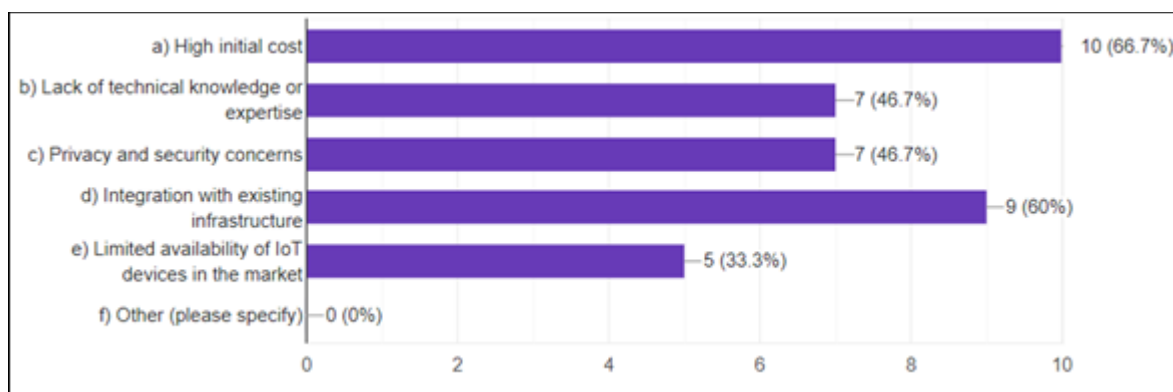
2) Key areas of sustainability contribution of IoT



According to the survey more than 50% of students think that IoT will be able to help in the energy efficiency industry. This is because the energy crisis is one of the issues most people are easily able to relate to. Moreover, education about the use of technology in energy conservation is more widely discussed today. Moreover,

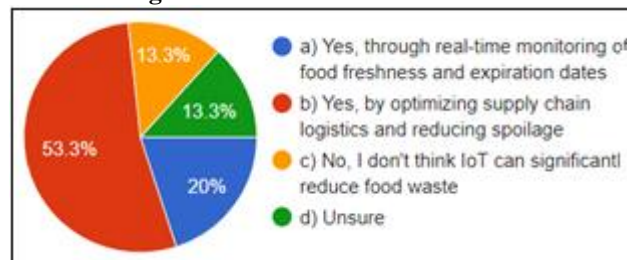
there are already efficient IOT devices used to make energy sources like solar panels more efficient.

3) Challenges faced while adopting IOT solutions for sustainability purposes

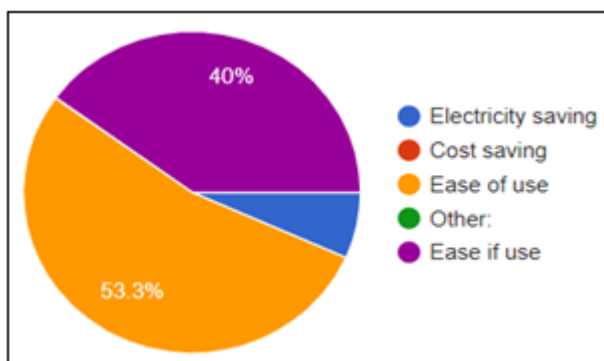


We can see that 10 out of the 15 people who submitted the form thought that the initial cost of IOT devices was too high. This may be because technology today is really expensive for the common man. But according to many digital companies as the demand for the technology increases in the future and companies start producing more the cost of the goods will reduce.

5) Approaches through which IoT can play a role in minimizing food waste



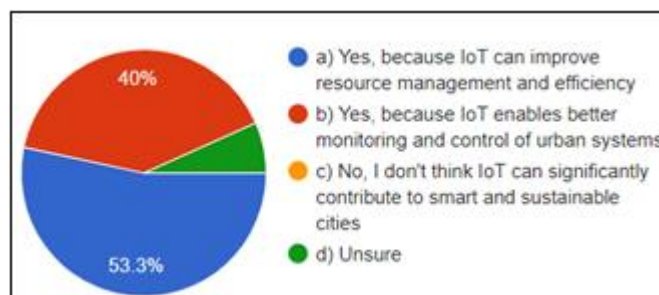
4) Aspects of our everyday lives where the Internet of Things (IoT) plays a helpful role



We can see that 93.3% of students believe that IOT is easy to use. This suggests that students find the user interface of IOT devices easy to use. This may be because the new generation is more open to new inventions such as IOT and takes an extra step to research and use it.

Only 2 people who responded believed that IOT could not help in reducing food waste this clearly shows that the new generation (students) believes in the power of IOT and thinks it can help us save future generations.

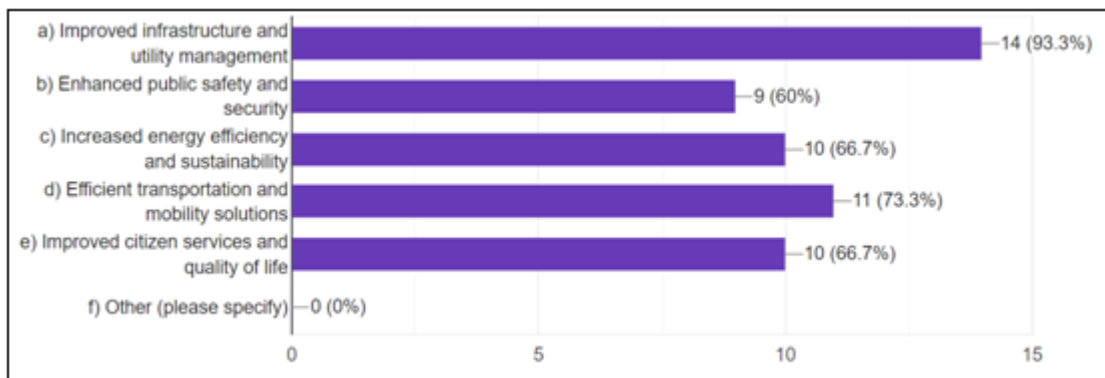
6) Contribution of the IOT toward the development of Smart and Sustainable Cities



In this question, we can clearly see that not even 1 student thinks that IoT will not make the future smart and sustainable. The primary reason for this is that even though IoT is not that developed right now it has made a lot of the appliances we use smart. A common example is “Alexa”.

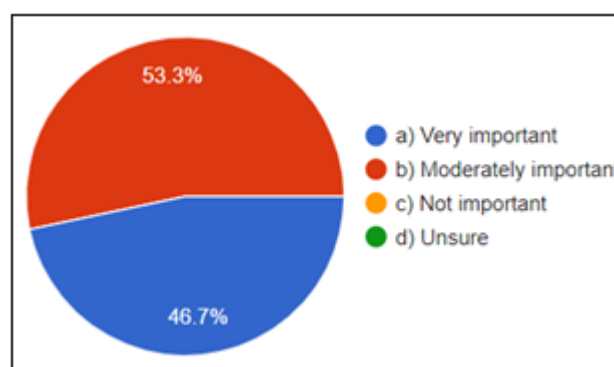
This is a voice assistant made by Amazon. It can control the entire house with the use of voice commands.

7) Potential benefits of implementing IOT in a smart city

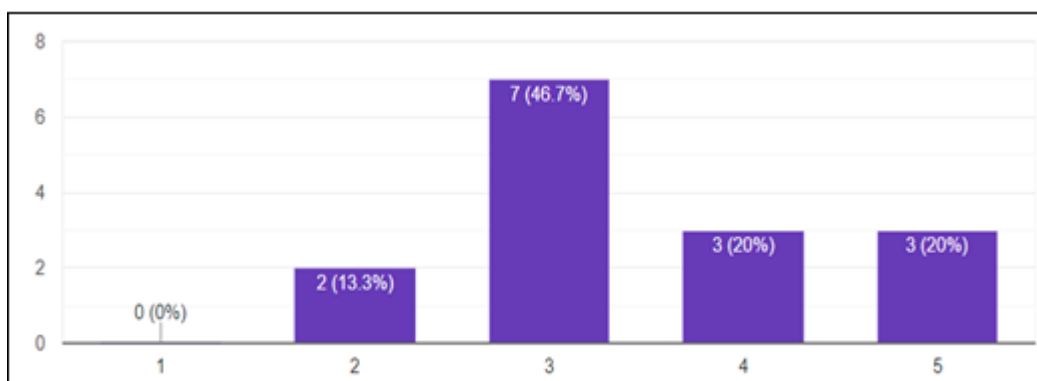


More than 70% of the students who took the survey believe that the use of IoT will make transportation and mobility more efficient in the future. This is mainly because it has been found that cars, and trucks today have really low fuel efficiency, with the introduction of IoT systems this could be brought up easily.

8) Importance of citizen engagement and involvement in the planning and implementation of smart city initiatives and community - based IOT projects promoting sustainable practices



100% of the students who filled out the survey know that it is very important for citizens to be engaged in the planning and implementation of smart cities. But we can see here that more than 50% of people are unlikely to participate in communicate - based projects.



4. Conclusion

In the realm of energy management, the strategic integration of the Internet of Things (IoT) emerges as a powerful driver for advancing energy efficiency. This research paper uses insights from data and industry professionals and concludes with a focused understanding of how IoT stands to improve sustainable energy practices.

Analyzing the data reveals a discernible upward trend in IoT adoption since 2011, signaling its growing significance across diverse industries. This foundational understanding

sets the stage for recognizing how IoT can play a pivotal role in fundamentally reshaping energy efficiency, as emphasized by the survey responses from industry professionals.

The survey underscores a clear awareness and interest in IoT technologies within the energy sector, particularly concerning efficiency improvements. A significant majority of professionals either have practical experience using IoT devices for energy efficiency or express a keen interest in doing so. This alignment between industry needs and IoT

capabilities underscores the pragmatic relevance of this technology in optimizing energy consumption.

Furthermore, the unanimous agreement among professionals about the substantial potential of IoT in energy applications, specifically in enhancing efficiency, is a compelling endorsement. This confidence is grounded in the tangible impact that IoT has demonstrated across various industries. With 60% assigning the highest rating on the potential scale, there is a collective belief in the transformative power of IoT for making energy use more efficient.

However, challenges and concerns, such as resistance to change, high implementation costs, and data privacy issues, accompany the integration of IoT into energy management practices. These challenges underscore the need for strategic planning and proactive measures to ensure the seamless assimilation of IoT, ultimately leading to increased efficiency.

Looking at the timeline expectations, professionals are cautiously optimistic, anticipating efficient IoT use within the next 1 - 5 years. This timeline aligns with the urgent need to address energy efficiency concerns and reduce waste. It reflects a belief in the maturation of IoT technologies for practical, real - world applications in energy efficiency.

Examining the perceived benefits of IoT in energy management, automated energy optimizations, and demand response emerge as crucial advantages directly linked to efficiency gains. This underscores the potential for IoT to bring about dynamic and responsive energy consumption practices, aligning energy use precisely with actual needs. The emphasis on real - time monitoring and control further underscores the importance of data - driven insights in achieving enhanced energy efficiency.

Moreover, the belief that IoT can drive behavior changes among professionals indicates a broader acknowledgment of its potential societal impact. As professionals witness the tangible benefits of IoT in reducing energy consumption and costs, a natural shift in behavior toward more sustainable and efficient practices becomes not only likely but necessary.

In conclusion, the synthesis of data and professional perspectives paints a picture where IoT is on the brink of large - scale integration into energy management practices, particularly in the pursuit of greater efficiency. The potential of IoT is not just theoretical but grounded in real - world applications and industry expectations, highlighting its pivotal role in shaping a sustainable future where energy is used with utmost efficiency.

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