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Futuristic investigative study of IoT/Green IoT as a driving force for sustainable development

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Abstract

Background/Objectives: Current wave of technological innovations like IoT/Green IoT (G-IoT) has opened doors for new possibilities that must be explored for achieving Sustainable Development Goals (SDG's) designed by United Nations. The main objective of the study is to propose an inference regarding potential role of IoT in achieving the target of sustainable development worldwide. **Methods/Statistical analysis:** An Online survey among the IoT industry experts, researchers, faculty members and educationists working in the area of IoT of 'A' grade state university in India has been conducted using 'Google Forms Questionnaire' to gain an insight into significance of G-IoT for sustainable development. The number of survey participants were around 300. **Findings:** The study attempts to track the gaps, challenges and obstacles in attaining the target of SDG's. The major findings of the paper depict the significance of IoT in achieving the SDG's as 84% respondents believes that that Green IoT/ Green ICT technologies can act as a game changer in accomplishing sustainable development and growth of green economy. Major areas where we can take advantage of these technologies include productive and efficient utilization of raw materials along with preserving natural resources and minimizing the emission of greenhouse gases and other wastes. **Novelty/Applications:** A sustainable environment around the world demands the planned and organized usage of IoT and G-IoT concept towards constructing/developing the goods and services for enhancing renewable energy sources, energy-conserving computing, management of power sources, green metrics, assessment tools and methodologies have potential to significantly transform the traditional development into sustainable development. **Keywords:** Sustainable development; Green IoT; IoT devices; technological innovations

1 Introduction

Latest technologies and the upheaval of Internet of Things (IoT) has fueled up research in almost all areas related to human beings, disseminating anytime, anywhere, any device information access to human beings in different ways. This phenomenal

research in recent decades aims to synergize human, data, processes and things, organizations, places, services and facilities together in exceptional ways. Although IoT offers ample of benefits to human society, still the process of manufacturing, utilization, implementation and distribution of IoT services and devices requires voluminous energy and resource ultimately producing ever-increasing toxic electronic waste. To attain the target of sustainable development, plans are being developed at national and international levels keeping in mind the environmental, social and economic aspects. The coming era of revolution is Green Internet of things (G-IoT). Still, there is very low indication of IoT advancements in many developing countries⁽¹⁾.

Green usually means "planning and investing in a technology network that serves the needs of today as well as today's needs while conserving energy and saving money." The Green Internet of Things focuses primarily on the energy efficiency and the reliability of the IoT concepts. "Green IoT is defined as the energy-efficient way in IoT to either reduce or eradicate the green-house effect caused by existing applications. Green IoT is the process of efficiently producing, developing, disposing of computers, servers, using and associating subsystems (i.e., printers, displays, communications equipment and storage devices), with a reduced negative impact on society and the environment"⁽²⁻⁴⁾.

2 Need of IoT/ Green IoT

The term 'Internet of Things' was first coined by Kevin Ashton as title of his PowerPoint presentation. Kevin had shared an idea of using "RFID (Radio Frequency Identification)" chips on consumer goods for automatically tracking the stock levels in the storehouses. Afterwards, Internet of Things (IoT) became an emerging concept and revolutionized the world by connecting billions of IoT devices together. The IoT devices work by sensing, collecting, and transmitting the vital information gathered from the surroundings. IoT has also brought some of the obstacles to the Environment. For the natural environment, the most important issues are increasing the volume of e-waste, energy consumption and CO₂ emissions^(1,5).

To mitigate the potential negative impacts of latest scientific developments in area of IoT on human society and environment, it has become mandatory to effectively deal with the threats and challenges posed by IoT. These challenges mainly include enhanced energy consumption, generation of electronic waste, emission of greenhouse gases mainly CO₂, utilization of non-biodegradable materials for IoT devices, usage of non-renewable and natural raw materials⁽⁶⁻¹⁰⁾. This situation has created a need for moving towards Green IoT (G-IoT), a future technological enhancement of IoT associated with green technology and green economy⁽¹¹⁻¹⁴⁾. Green IoT is aimed towards bringing notable improvements in environmental and human well-being so as to make the world smarter using sustainable technological developments. G-IoT is the need of the hour and it carries the potential to completely transform the human society along with improving environmental health. G-IoT is the latest technology that emphasizes on developing solutions towards eliminating or mitigating the negative influences on the people's health and the environment. Green IoT (G-IoT) basically focuses on two aspects. The first aspect is oriented towards "designing IoT computing devices, communications protocols and networking architectures" that are energy efficient. The second aspect is oriented towards leveraging IoT technologies to reduce emissions of greenhouse gases, radiations and pollution. Using the technological advancements in IoT enabling technologies, Green IoT has great capability to strengthen environmental and economic sustainability. There is a great need and importance of green technologies and green processes in sustainable development and building a smart world.

Green usually means "planning and investing in a technology network that serves the needs of today as well as today's needs while conserving energy and saving money." The Green Internet of Things focuses primarily on achieving energy proficiency and the trustworthiness of the IoT concepts. "Green IoT is defined as the energy-efficient way in IoT to either reduce or eradicate the green-house effect caused by existing applications. Green IoT is the process of efficiently producing, developing, disposing of computers, servers, using and associating subsystems (i.e., printers, displays, communications equipment and storage devices), with a reduced negative impact on society and the environment". Going for green IoT requires new resources to reduce the negative impact of IoT on human health and disrupt the climate. Greening IoT's primary goal is to reduce CO₂ emissions and waste, harness environmental conservation and mitigate the costs of operating stuff and power consumption. Reduction of the energy consumption of IoT devices is required to make the world healthier. Green IoT offers a great possibility/opportunity to assist in achieving new economic heights and highly sustainable environment through the advancement of greening ICT technologies.

Major Objectives of Green IoT are:

1. Energy Efficient Procedures Adopted by IoT
2. Reduce Green-house effect of Existing IoT Applications
3. Reduce Energy Consumption and CO₂ emission
4. Electronic waste management
5. Usage of Surrounding Environment to assist in generating power supply

Green IoT can be defined as “The study and practice of designing, using, manufacturing, and disposing of servers, computers, and associated subsystems such as monitors, storage devices, printers, and communication network systems efficiently and effectively with minimal or no impact on the environment.”

3 IoT/Green IoT for sustainable development

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Green IoT revolves around the cross-cutting technologies “Design technologies, Leverage technologies and Enabling technologies” to support and achieve sustainable development as shown in Figure 1.

- Design Technologies – Focuses on generating energy preserving efficient systems, efficient transmission protocols, low power needs for network architectures, and other cross-connections.
- Leverage Technologies applies to reducing carbon releases and increasing energy conservations.
- Enabling technologies include various technologies such as machine-to-machine networking, sensor and cellular networks, green RFID, energy reaping and communication tools, cloud computing, intelligent radio transmissions and analysis techniques for big data. With these enabling technologies, green IoT offers boundless opportunities to boost environmental and financial performance^(15–18). [Figure 1] In 2015, the United Nations signed the Agenda 2030 for Sustainable Development (SDG), through 17 Sustainable Development Goals as depicted in Figure 2. The meeting of United Nations with Members States in 2015 concluded that there is an emergent need of the hour to set up a common blueprint for survival of world population with immense peace and affluence in the future. The blueprint for the same was presented with a Common Agenda for sustainable growth by 2030^(19–22).

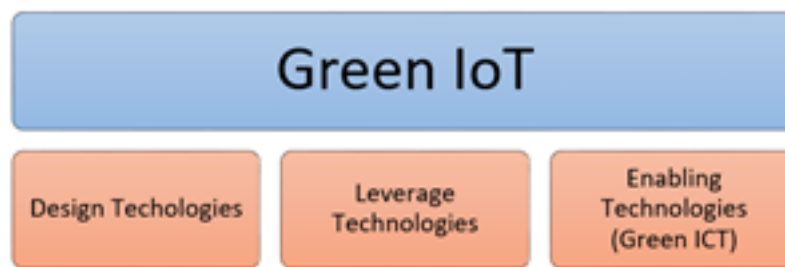


Fig 1. Green IoT technologies

The idea behind this was to collaborate and synergize the efforts of the nation's worldwide towards achieving the 17 “Sustainable Development Goals (SDGs)” by 2030. The success to attain these 7 SDG's around the world highly depends on the level of global association and understating among nations, immediate proactive contribution and implementation by all developing and developed countries, developed and emerging^(19,23). [Figure 2]



Fig 2. Sustainable development goals defined by United Nations

4 Objectives of sustainable development

Sustainable development is the aim of safeguarding sustainable development, social equality and justice, and environmental conservation. While these three variables can operate in harmony, they are often found to interfere with each other. Economic growth for a better standard of life has been instrumental in destroying the climate throughout the second half of the 20th century. We are currently in a situation where we use more energy than ever before and waste products pollute the Planet. More recently, society has evolved to understand that with so much poverty and environmental destruction, we do not exist in a stable society or economy. Economic growth will remain the cornerstone of human progress, but it must adapt to become less harmful to the ecosystem. In order to bring this understanding into effect, the challenge of sustainable development is to turn our inefficient ways into more sustainable ones^(24,25).

The main objective of Sustainable development is to create and maintain certain kind of balance between the social, financial and environmental requirements of the society so as to enable the prosperity among the current and upcoming generations. Sustainable development talks and focuses on long term effects and consequences of any decisions taken regarding technological, social, financial or social development. The basic idea is to actually build up a stable and sustainable societal infrastructure by resolving all the possible conflicts in terms of economic, social and environmental developments along with preservation of key natural and man-made resources. [Figure 3]



Fig 3. Objectives of sustainable development

5 IoT for sustainable development: A futuristic study

To mitigate the potential negative impacts of the latest scientific developments in area of IoT on human society and environment, it has become mandatory to effectively deal with the threats and challenges posed by IoT. These challenges mainly include enhanced energy consumption, generation of electronic waste, emission of greenhouse gases CO₂, utilization of non-biodegradable materials for IoT devices, usage of non-renewable, and natural raw materials. This situation has created a need for moving towards Green IoT (G-IoT), a future technological enhancement of IoT associated with green technology and green economy. Green IoT is aimed towards bringing notable improvements in environmental and human well-being to make the world smarter using sustainable technological developments. G-IoT is the need of the hour and it carries the potential to completely transform human society along with improving environmental health. G-IoT is the latest technology that emphasizes on developing solutions towards eliminating or mitigating the negative influences on the people's health and the environment. Green IoT (G-IoT) focuses on two aspects. The first aspect is oriented towards designing IoT protocols, frameworks and devices for conservation of energy. The second aspect is oriented towards leveraging IoT technologies to reduce emissions of greenhouse gases, radiations, and pollution. Using the technological advancements in IoT enabling technologies, Green IoT has great capability to strengthen environmental and economic sustainability.

A WEF (World Economic Forum) report stated in 2018 that 84% of IoT deployments were addressing or had the potential to address the SDGs. Among the 17 Sustainable Development Goals, the following SDGs as those addressable by most of the IoT projects^(20,26,27). [Figure 4]

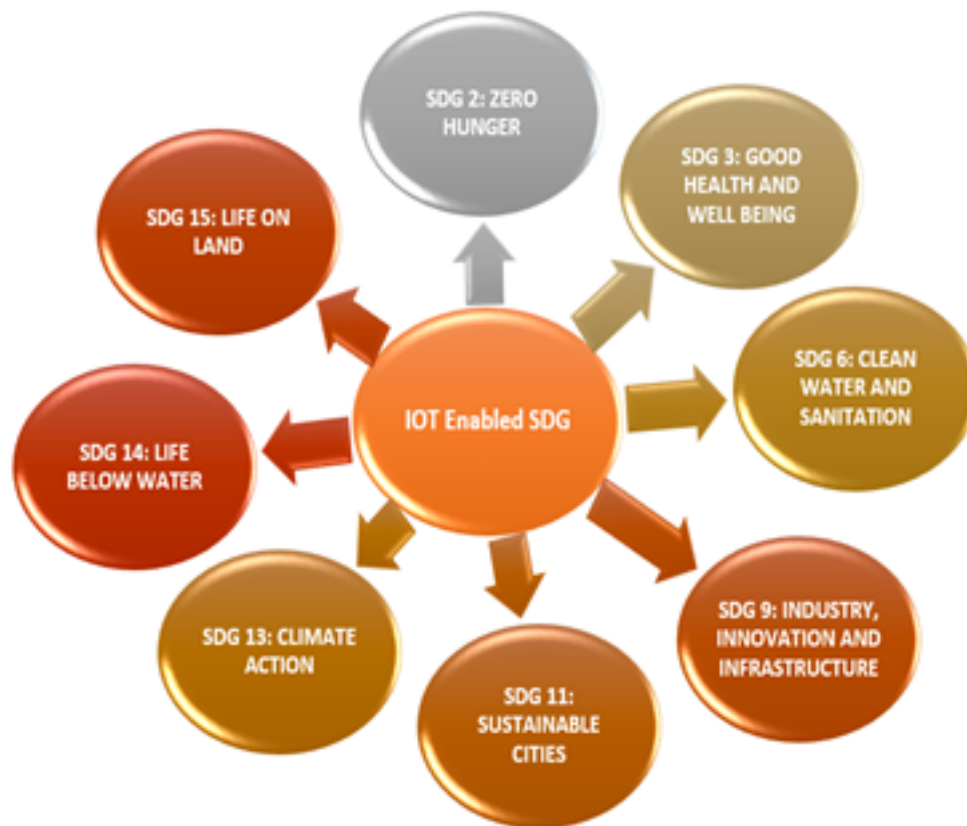


Fig 4. IoT enabled sustainable development goals

5.1 Survey design and result analysis

An online survey using ‘Google Form Questionnaire’ was conducted among the IoT industry experts, researchers, professors, educationists of ‘A’ grade state University in India to gain insight into possible future implications of IoT applicability towards achieving the goal of sustainable development. 300 participants who possess the domain knowledge of Green IoT, sustainable development and other similar practices were selected for the survey. The results obtained have been graphically depicted to easily capture the current need/challenges that need to be addressed with immediate effect at each level namely: government and state level, corporate level, society level, and at the individual level to achieve the Sustainable Development Goals (SDG’s) designed by United Nations by 2030.

Q1: How do you rate the importance and significance of IoT in successfully implementing the Sustainable Development Goals (SDGs) defined by the United Nations?

IoT innovations are capable of processing data intelligently, making proficient and successful communication thus converting machines into smarter, efficient and sustainable devices. Reducing the energy usage of IoT devices is needed in order to make the world healthier. Green IoT has a great potential to promote economic growth and environmental sustainability through the advancement of green ICT technologies. 84 % of respondents have concluded that IoT/Green IoT can play a significant and phenomenal role in achieving the goals of sustainable development. [Figure 5]

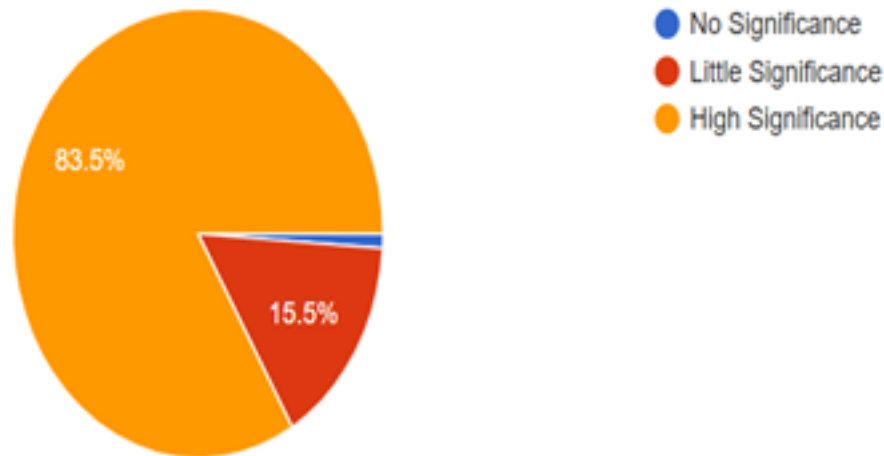


Fig 5.

Q2: Do you agree that IoT is essential and Indispensable for achieving the Sustainable Development Goals (SDG's)?

31% of the respondents strongly agree and 65% agree that the use of IoT technology/devices/applications is essential and indispensable to attain the target of sustainable growth. This will be possible only if global/national and regional efforts are streamlined to accomplish sustainable development. Developed countries must endorse/assist and encourage the developing countries to design, develop, implement, share and disperse competent technologies to safeguard the environmental sustainability on flexible terms and conditions. [Figure 6]

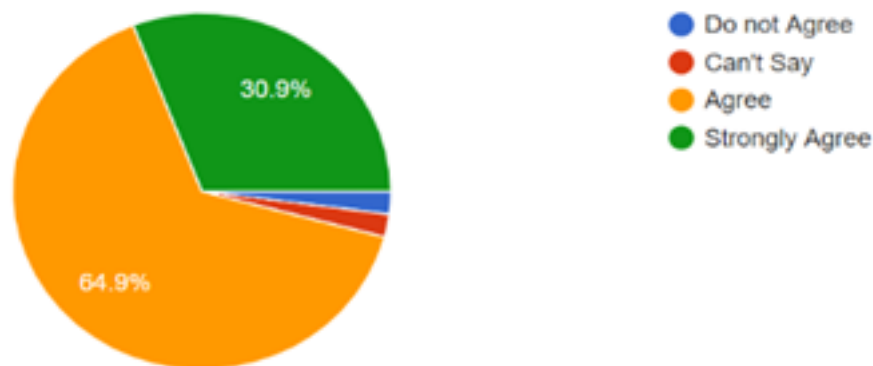


Fig 6.

Q3: Do you agree that Government/Industrial Policies like “research promotion, Encouraging the development and implementation of IoT Technologies” can highly influence the results of utilizing “IoT for achieving the Sustainable Development Goals (SDG's)”?

As it is depicted from survey results, it is obvious that researchers and educationists are aware that the IoT projects/applications whose main objective is to mitigate the challenges and threats posed for sustainable development, still prioritizing the sustainability goals inside commercially driven projects in Industries can assist in increasing this impact. Approx. 90% of respondents confirm that industrial research promotion and encouraging policies of government for development and deployment of IoT applications can play a major part. [Figure 7]

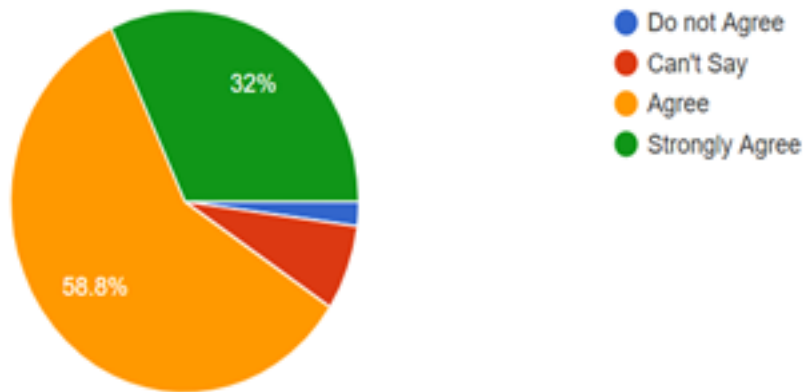


Fig 7.

Q4: Do you agree that the need for the hour is to incorporate "IoT for Sustainable Development Goals (SDG's)" in Education? Embracing a sustainability awareness culture is essential. Approximately 90% of the respondents believe that the education system urgently needs to incorporate "IoT for Sustainable Development Goals (SDGs)". Knowledge and awareness among the students regarding responsible resource consumption and sustainable environment along with logical capacity and ability of technology based problem-solving will help in achieving sustainable goals. [Figure 8]

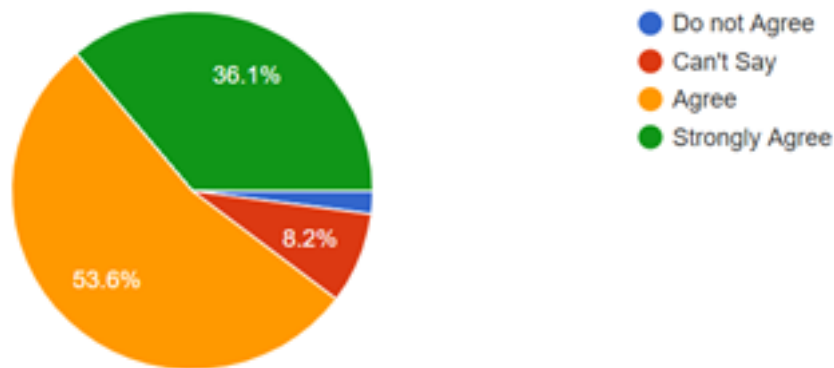


Fig 8.

Q5: To what extent "Adopting new and innovative IoT applications to deal with challenges associated with hunger, water supply, and food security through resource monitoring to cope with the increasing consumption needs of a global population" can assist in achieving Sustainable Development Goals (SDG's)?

68% of Respondents believe that adopting the latest and modern IoT applications can greatly assist in dealing with challenges like food and water scarcity. Any kind of water leakage can be detected, monitored and prevented using sensors. Similarly, other IoT technologies can easily be implanted to detect humidity of soil, probable water contamination, weather status monitoring, remotely handling the equipment's for irrigation etc. This can greatly boost up the overall sustainability, cost-effectiveness and energy efficacy of agriculture production by enhancing the quality and quantity of crop production. [Figure 9]

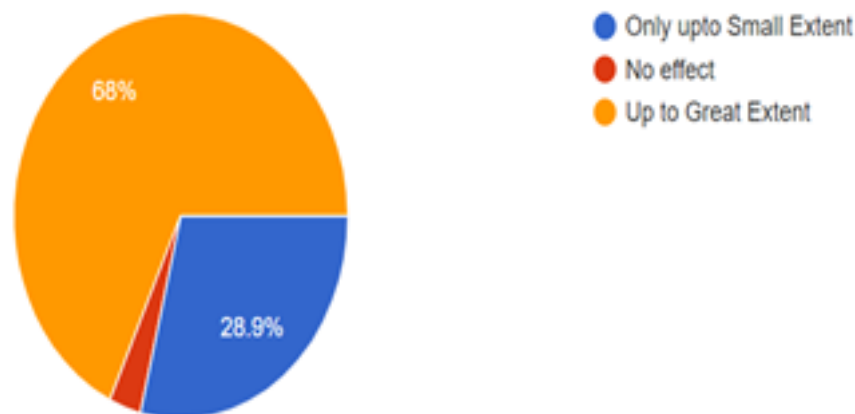


Fig 9.

Q6: Do you agree that "Promoting international dialogue and cooperation on the IoT for sustainable development by bringing the various stakeholders together, especially the academic and research community" can play a major role in achieving SDGs?

Every nation has a primary responsibility to make its social and economic development. There is a great importance of international financial institutions in supporting the policy space of each country in particular developing countries, in accordance with their mandates. Almost 87% of respondents either strongly agree or agree that international collaboration industrial, academic and research fronts for specifically designing IoT products prioritized with achieving sustainability goals will greatly help to attain the sustainability targets. [Figure 10]

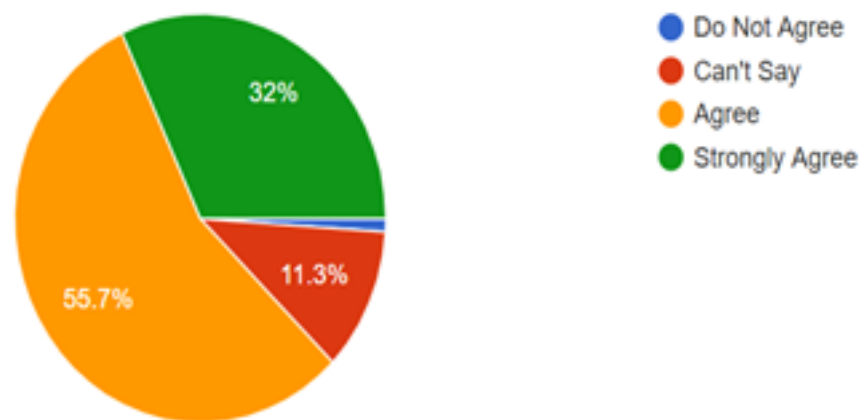


Fig 10.

Q7: Do you agree that Sustainable development demands that "we humans reduce all sorts of waste including electronic waste".

A huge source of embodied energy is the production of the IoT and other electronic devices and the use of rare materials which go into their production. E-waste minimization helps to save resources and decreases the amount of energy that we take from the earth. Instead of making or extracting more of them alone, recycling/reusing the precious metals and plastics in old mobile phones will save as much energy as flipping off the electricity to 24,000 US homes for a whole year. 46% of respondents strongly agree and 44% agree to the fact that minimizing all sorts of wastage including plastic/metal/other electronic waste in IoT devices can play a major game-changer in attaining the target of sustainable development. [Figure 11]

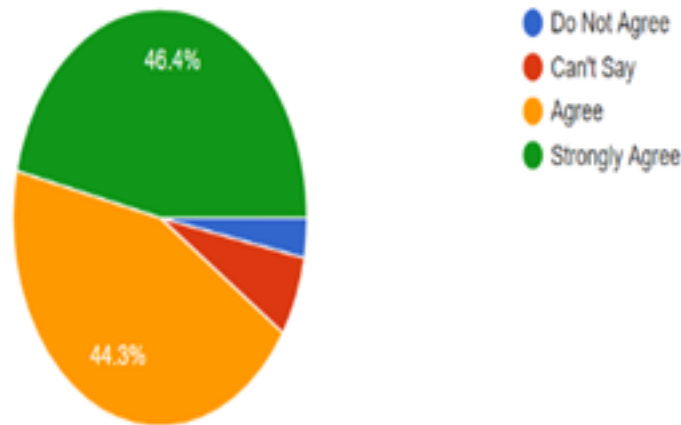


Fig 11.

Q8: Do you agree that “Sustainable Development demands that we switch to renewable resources (renewable resources include, for example, wind power, solar panels, ethanol, cardboard packaging.)”

Over the last four decades, the world has witnessed an interesting new trend. Technologies have been designed and engaged solely to make the world a better place. Industries have developed/focused around clean energy such as wind and solar energies. Approximately 92% of respondents believed that it is the emergent demand of the time to switch to the renewable energy resources that mitigate the negative impact on the environment like CO₂ emissions, greenhouse effects, global warming, etc. [Figure 12]

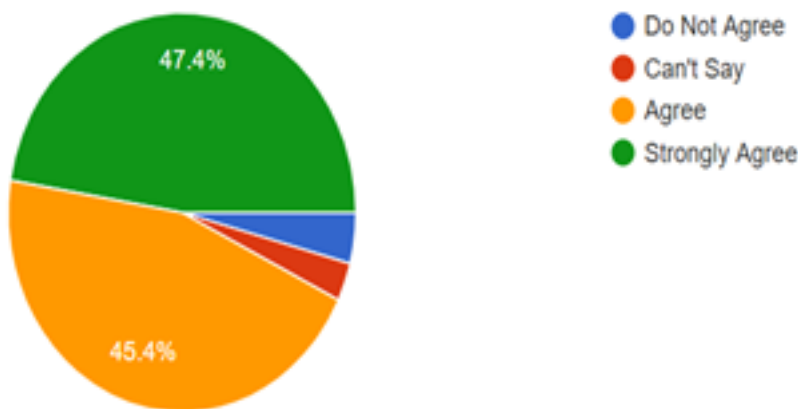


Fig 12.

Q9: Which of the following is the major challenge in achieving Sustainable Development Goals?

Results from Survey depicts that IoT is a wave of revolution to achieve sustainable growth and development. However, there is still a slight indication of progressing IoT in developing countries. 58% of respondents believe that “The Governance issue” is a major hurdle in the successful implementation of IoT for sustainable growth. Therefore, making policies for investors/tech-entrepreneurs/officials/administrators is much needed to transform the implementation of IoT applications into long term practices. [Figure 13]

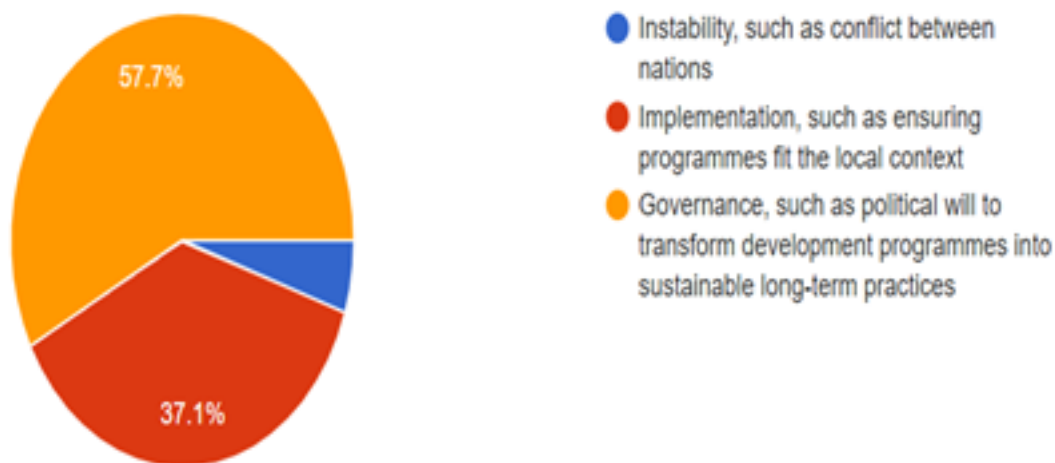


Fig 13.

Q10: Rank the following “IoT Practices for Sustainable Development” as per their need and significance

“IoT for biodiversity conservation and ecological monitoring”

“IoT for smart and sustainable cities through global initiatives”

“Promoting international dialogue and cooperation on the IoT for sustainable development”

“Promoting the development and adoption of IoT technologies”

“Supporting the implementation of the IoT in an urban and rural context”

“Adopting new and innovative IoT applications to deal with challenges associated with hunger, water supply, and food security”

“Galvanizing interest in the use of IoT for risk reduction and climate change mitigation”

“Identifying and incorporating IoT technologies for Sustainable Development” in education”

64% of respondents have allotted the highest priority to the sixth option of “Adopting new and innovative IoT applications to deal with challenges associated with hunger, water supply, and food security”. 58% of respondents chose second priority “IoT for smart and sustainable cities through global initiatives”. “Half of humanity – 3.5 billion people – lives in cities today and 5 billion people are projected to live in cities by 2030. The world’s cities occupy just 3% of the Earth’s land but account for 60-80% of energy consumption and 75% of carbon emissions”⁽²⁷⁾. [Figure 14]

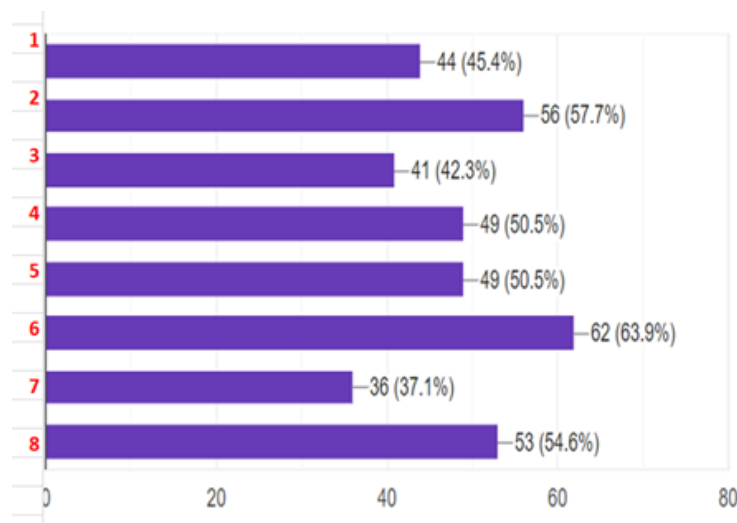


Fig 14.

The Sustainable Development Goals and Priorities will promote action over the next ten years in the following areas where IoT technologies are important for humanity and the earth. The analysis of survey results concludes that the following points need urgent focus and attention to achieve sustainable development. Going for green IoT requires new resources to reduce the negative impact of IoT on human health and disrupt the climate. Greening IoT's primary goal is to reduce CO₂ emissions and waste, harness environmental conservation, and mitigate the costs of operating stuff and power consumption. The reduction of the energy consumption of IoT devices is required to make the world healthier.

Green IoT offers a high potential to support economic growth and environmental sustainability through the advancement of greening ICT technologies as depicted in Table 1.

Table 1. Summary of Survey Results

Role of IoT in Sustainable Development	<i>Ans 1: IoT is highly significant in successfully implementing the Sustainable Development Goals (SDG's) defined by United Nations.</i>
	<i>Ans2: IoT is essential and Indispensable for achieving the Sustainable Development Goals (SDG's).</i>
	<i>Ans 3: Government/Industrial Policies like "research promotion, Encouraging the development and implementation of IoT Technologies" can highly influence the results of utilizing "IoT for achieving the Sustainable Development Goals (SDG's).</i>
	<i>Ans 4: Need of the hour is to incorporate "IoT for Sustainable Development Goals (SDG's)" in Education.</i>
	<i>Ans 5: Adopting new and innovative IoT applications to deal with challenges associated with hunger, water supply, and food security through resource monitoring to cope with the increasing consumption needs of a global population" can assist in achieving Sustainable Development Goals (SDG's) up to great extent.</i>
	<i>Ans 6: Promoting international dialogue and cooperation on the IoT for sustainable development by bringing the various stakeholders together, especially the academic and research community" can play a major role in achieving SDG's.</i>
	<i>Ans 7: Sustainable development demands that we humans reduce all sorts of waste including electronic waste.</i>
	<i>Ans 8: Sustainable Development demands that we switch to renewable resources (renewable resources include, for example, wind power, solar panels, ethanol, cardboard packaging.)</i>
	<i>Ans 9: Governance issues are major challenge in achieving Sustainable Development Goals.</i>
	<i>Ans 10: Adopting new and innovative IoT applications to deal with challenges associated with hunger, water supply, and food security.</i>

6 Recommendations

Based on the detailed Literature study and Survey results, the following recommendations can be pinpointed:

1. Need for management of "Exa-flood" or "Data Deluge": Explosion of the huge amount of data collected and exchanged through IoT network devices.
2. There is an emergent need for reaching a "zero level of entropy" where the IoT systems or devices are designed in such a way to harvest its own energy.
3. Need for Miniaturization of IoT devices is popping up as an urgent requirement for achieving SDG's.
4. Need for Development of Autonomic Resources that are capable of self-healing, self-management, self-configuration.

7 RoadMap for future studies

Future lies in the fact that countries around the world must jointly focus on research and development of “Smart and Intelligent Objects Everywhere” beyond the concepts of smart cities and smart buildings in order to attain the target of SDG's by 2030. Smart and biodegradable IoT devices/biodegradable batteries with Nano power processing units must be developed to unlock full potential of IoT in a positive and sustainable way for building a smarter, healthier and sustainable world. Following research trends will stimulate the future advancements of smart systems: “the increased use of embedded intelligence in IoT devices and the networking of embedded intelligence.”

8 Conclusion

The survey conducted in the present research work concludes that “All the research work in IoT sector towards design and development of IoT devices/software's/techniques will not generate long-term benefits to the society unless the research focus do not take Green IoT into consideration, as Green IoT is one of the strongest pillar for achieving the target of sustainable development.” The survey results depict that 75-90% percent of the researchers/educationists are in favor of making the “IoT developments” as “Green IoT developments” for long term benefits. The limitation of the current study is that the survey results have been calculated using a medium size sample population. Future studies in this direction may generalize the results on a larger sample size. The present study will add to the IoT/Green IoT body of knowledge as similar studies have not been conducted in this area in past.

Correct decisions regarding technological innovations taken at initial stages of the development can assist in realization of idea of sustainable world. Technology has become inseparable part of sustainable development as it can be used as a tool for handling assets existing in nature in well planned and well-organized way, providing access to clean and affordable energy, clean water, possibility to survive in a least polluted environment and have effective environmental governance managements. The realization of a sustainable world vision through technological research and innovations can only be achieved by making “right” choices at an initial phase of their development. The need of the hour is to utilize technologies to develop as an obligatory tool for sustainable development. The areas where these can prove beneficial are numerous like maximizing the usage of raw materials and decline of GHG emissions and waste along with preserving natural assets/resources. Traditional development can be considerably transformed into sustainable development by deployment of the IoT and G-IoT concept, by using specifically designed products and services for a sustainable environment. The focus of implementation of IoT for sustainable development can only be fruitful when global, national, regional, and individual efforts are streamlined to collaborate and co-operate for the promotion of innovatively designing and implementing IoT devices. The green-IoT deals with keeping the environment green and clean by mitigating the negative impact of IoT on the environment. This paper surveyed to investigate the issues/challenges that need to be addressed urgently to attain sustainable development goals defined by the United Nations by 2030. The analysis of survey results affirms that IoT can play the role of a game-changer in attaining the target of sustainable development. Moreover, IoT is essential and indispensable.

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