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Exploiting Internet of Things to address climate change: Case study and analysis on the perception of stakeholders in Pakistan

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ABSTRACT

This paper presents a first of its kind, regional study on perceptions of stakeholders on the use of internet-of-things (IoT) technology to address climate change in Pakistan. The aim of this study is to measure the stakeholders' awareness and willingness to adopt IoT technology for climate monitoring and change mitigation. The methodology includes identification of stakeholders, design of a structured questionnaire for quantitative research, data collection from identified stakeholders and analysis of the collected responses It is identified that there is a need for capacity building on IoT and climate change. This is required for increasing collaboration between academic and IoT industry for development of solutions among IoT companies. The study also highlights role of regulatory standards in Pakistan for manufacturing and deploying IoT technology. Based on our findings through this investigation, we have provided recommendations for Governmental and professional bodies on the need to formulate effective and encouraging policies and regulations. Moreover, we have also made recommendations pertaining to industries and vendors, aimed at achieving sustainable development goal by ensuring resilience to climate change across the country through the use of IoT technology. We have also provided the recommendations for academia and research for better capacity building in this domain.

1. Introduction

Dimensions, which include societies, environment, economies, and public health. Driven primarily by human activities (burning of fossil fuels, deforestation, and industrial processes releasing greenhouse gases (GHG) into the atmosphere), the changes in the Earth's climate have been significant. Some of the key areas where climate change has impacted the world are shown in Figure 1. The impacts of climate change are complex, emphasizing the need for comprehensive and collaborative efforts, policy interventions, sustainable practices, and technological innovations to address this global challenge. The governments, experts, researchers, and industry have therefore been debating on methods to mitigate and adapt to this change.

According to the latest report published by United Nations Human Settlements Programme, Pakistan ranks as the fifth most vulnerable country to climate change according to global climate risk index [1]. The impacts of climate change in Pakistan are apparent in the form of increasing frequency of floods, droughts, extreme weather events, increased natural disaster, scarcity of natural resources, altering natural ecosystem and loss of biodiversity. These changes have severe consequences for Pakistan's agriculture sector and water resources, posing substantial economic and livelihood challenges. Additionally, the accelerating urbanization leads to several environmental degradations such as air and water pollution, industrial waste and inefficient use of energy. Hence, the immediate task for Pakistan is to understand the importance of climate resilience and to policy interventions for the mitigation and adaption actions of climate change [2]. Accordingly, the Ministry of Climate Change, Government of Pakistan, formulated the National Climate Change Policy in 2012 [3]. Following, the 'Paris Agreement'[4] and Sustainable Development Goal (SDG) 13 of 'The 2030 Agenda for Sustainable Development' by the United Nations Development Program [5], the policy has been updated in 2021 with the focus of mitigation and adaptation to climate change with emphasis on green solutions which includes adopting renewable energy sources, reforestation and sustainable agriculture [6].

On the other hand, the World Meteorological Organization (WMO) and International Telecommunication Union (ITU) has outlined the potentials of Information Communication Technologies (ICTs) for monitoring the variables affecting global climate [7], [8]. Internet of Things (IoT) is the enabling technology behind smart energy management, renewable energy integration, precision agriculture, smart transportation, smart health and industry 4.0 [9]. [10] and [11] reported that the adoption of IoT industry in Pakistan is experiencing a growth, due to smart, sustainable city initiatives by the government. The IoT market in Pakistan is further anticipated to achieve a revenue US$7.41bn [12]. IoT technology offers powerful solutions to combat climate change by enabling real-time data collection, analysis, and informed decision-making.

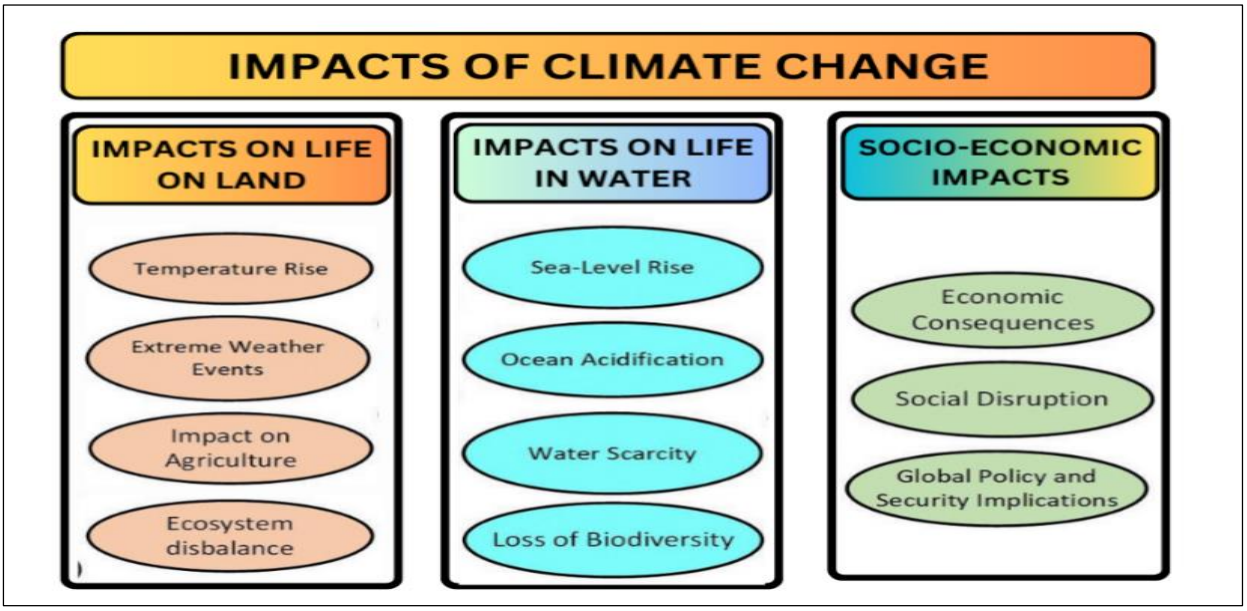


Figure 1: *Illustration of different impacts associated with climate change.*

Deploying IoT sensors for climate monitoring and early warning systems equips us to respond proactively to environmental changes and mitigating the impact of extreme weather event. Therefore, embracing IoT potential can lead us towards a more sustainable and resilient future, where we can effectively address the challenges posed by climate change.

In the last few years, several initiatives have been undertaken in Pakistan to conduct studies and surveys in order to gauge awareness of stakeholders and also analyze the interventions being done by them to handle climate anomalies. The authors in [13], conducted survey with farmers in Khyber Pakhtunkhwa regarding climate-related challenges and identified that households have implemented adaptation methods to combat these changes such as adjusting fertilizer use, altering crop types, and planting shaded trees that aim to mitigate these risks at the household level. M. Abid et al [14], [15] examined farmers' responses to climate change in Punjab based on data from 450 farm households. The study in [14], revealed widespread awareness of climate change, with 58% of farmers implementing adaptation measures. While, [15] highlights common climate-related risks recognized by farmers. The research emphasizes the necessity for improved institutional support and increased collaboration among farmers to strengthen adaptive capabilities. The authors in [16] have investigated the impact of climate change on the dairy sector in Pakistan. Farmers noted increased severity and frequency of extreme climate events with drought as a major risk affecting dairy production significantly. The study underscores the need for government policy initiatives to support long-term focus on climate resilience. A. Ajani [17] and M. S. Bacha [18], outlined the main climate stressors and their impact on frontline regions in Pakistan through structured questionnaire. Their study revealed native people perception of climate change and their adaptation action which can help policy makers about developing climate resilient framework based on experience and inclusion. According to survey conducted by UNICEF to examine youth's perception and experience on climate change [19], 73% of respondents were reported to be unable to explain climate change and global warming. The survey suggested advancing climate education and awareness through reforming national curriculum, teacher training and diverse pedagogical approaches. Authors in [20] assess moderate level of awareness regarding climate change among university student in Lahore, Pakistan. Similarly, [21]

determined insufficient knowledge and awareness regarding climate change and its impact among survey participants.

All of the above-mentioned studies [13]- [21], do not address the use of technology, in particular IoT to handle climate change. To fill this gap, we conduct this study, in accordance with the work in other countries who are facing similar adversaries of climate change reported in [22]–[25]**.** However, it is important to note that the climate change stressors and constraints of each environment are unique and policies developed by each country is based on its specific social, political and economic dynamics.

We have firstly identified our diverse stakeholders for whom we have to conduct this study. The main objective of this case study is to investigate the present perception and acceptance of stakeholders enabling IoT technology for mitigating climate actions particularly in Pakistan's environment. This allows us to identify the main drivers and benefits as well as the challenges encountered in introducing IoT technology for addressing climate change.

The findings and contributions presented in this paper are listed as following:

1. Through the survey conducted, we have presented a comprehensive analysis of the stakeholders' level of awareness and acceptance about IoT, and its relevance with climate change.
2. We have analyzed the challenges associated with the widespread adoption and deployment of IoT technology thereby defining enablers for integrating IoT solutions for climate change.
3. We have identified potential research and innovation areas where benefits of IoT technology can be utilized to address climate change.
4. We provide recommendations and suggestions for government and decision makers to formulate effective regulatory frameworks and policies to accelerate the efforts to embrace IoT technology for addressing climate change.

This paper is organized as follow, in section 2 we describe the design and methodology used to perform this research. In section 3 we provide results of our study based on the use of IoT for climate change, and draw insights based on our findings. Section 4 discusses various recommendations determined form in-depth study conducted in this work. Finally, section 5 provides a conclusion of this work.

2. Design and Methods

In this section, we have described the methodology undertaken to conduct the regional study. Figure 2 depicts the steps followed to successfully initiate and conclude the investigation into the stakeholders' perception on the use of IoT to address. Since our study investigates into stakeholders' perspective, implementation challenges thereby identify current state of adoption and policy framework, the research method is based on both exploratory and descriptive design. The technique employed in this quantitative research is based on purposive sampling. Diverse stakeholders were identified to maximize the impact of the study and included students, teachers, researchers, IoT service providers and IoT service customers. Closed-ended questions were structured for each stakeholder. For this purpose, one survey form (survey form A) was designed to acquire responses from people belonging to academic sector (teachers, researchers, and students). One survey form was designed to gauge understanding of IoT service providers (survey form B) and the third form was designed for professionals working in IoT service customers or (survey form C). Survey form A had 18 questions, while survey forms B and C had 20 and 22 questions respectively. The participation in this survey was voluntary and informed consent was

obtained from all participants, ensuring their data will be used for this study. The surveys for the pilot study were done using electronic communication (Google Forms). The links and QR codes for the said forms were shared direct and broadcasted through several channels which include:

- Emails to prospective respondents;
- Messages and posts on WhatsApp, Facebook, and LinkedIn platforms;
- Announcements during the awareness sessions on IoT based climate action which included a two-day international conference, IoT and STEM workshops;
- Face-to-face interaction with stakeholders.

Once the responses were collected, they were thoroughly analysed and results were obtained, providing an insight into the stakeholders' perception in the region. Section 3 below presents detailed results obtained through the survey and respective analytical discussion.

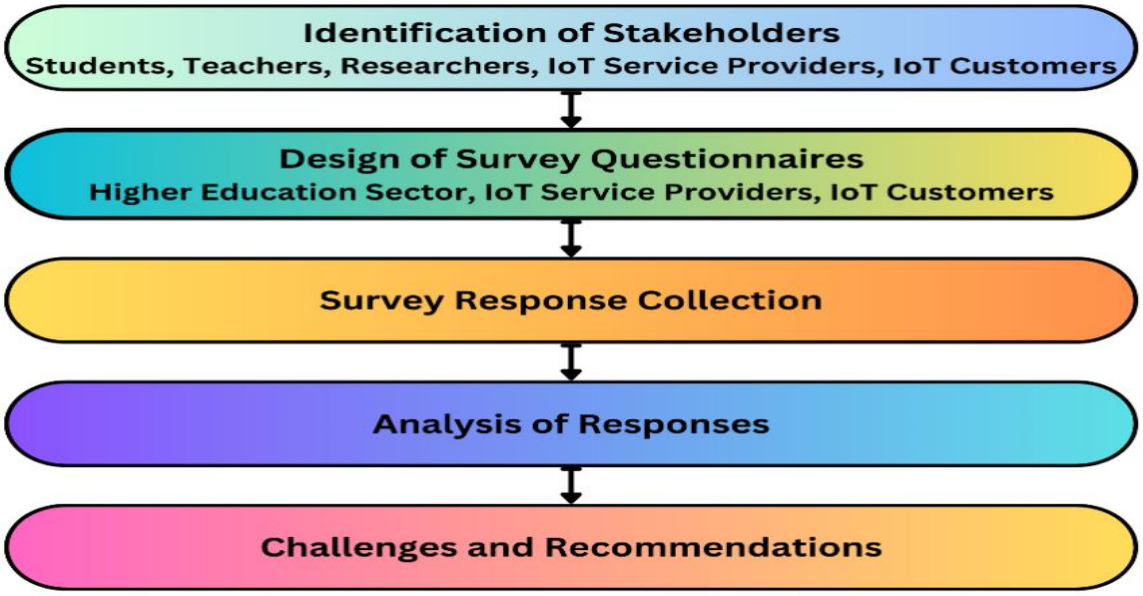


Figure 2: *Study design and methodology.*

3. Results and Discussions

In this section, we discuss the main results, analysis and finding of our survey as mentioned in following subsections.

3.1. Demographics of Stakeholders

For data collection purpose, the survey forms were classified into three categories namely (i) academic (faculty/researcher/students), (ii) industrial customers, and (iii) industrial service providers. Total 168 responses were recorded, out of which 160 respondents belong to academia whereas only few responses i.e. 08 were received from industrial stakeholders. The occupation of respondents along with the contribution in our survey is depicted in Figure 3. Our study is restricted to the participants coming from Pakistan region with 165 respondents from Sindh province, 02 respondents from Punjab and 01 from KPK. Table 1 summarizes the age group, gender and qualification of the survey respondents.

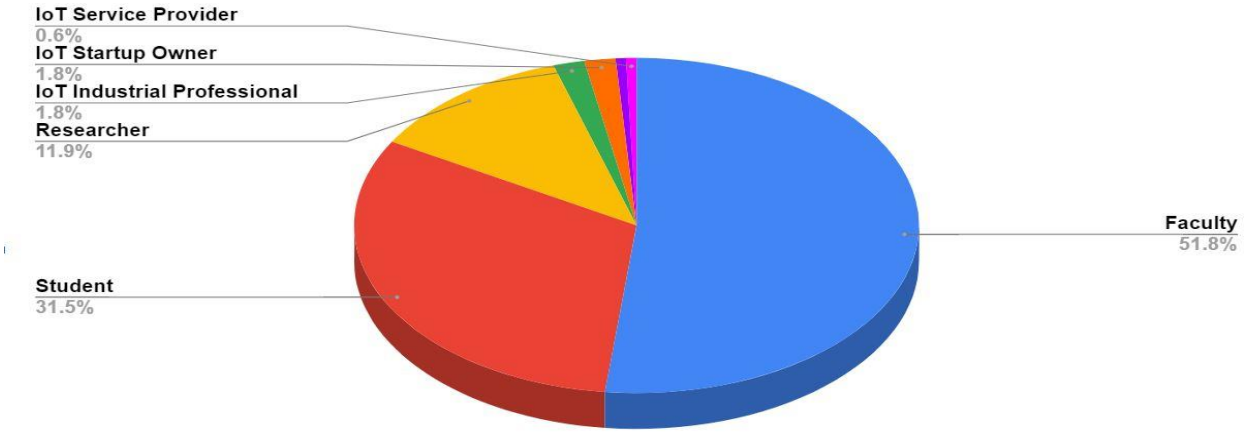


Figure 3: *Occupation of respondents.*

Table 1: *Demographics of survey respondents.*

Age	No. of Respondents	Gender		Education Level		
		Male	Female	Undergraduate	Graduate	Postgraduate or above
18-25	52	26	26	36	11	5
26-35	48	32	16	1	12	35
36-45	49	31	18	1	8	40
46-60	17	13	4	1	2	14
Over 60	2	2	0	0	1	1

It is evident from Table 1, that majority of participants are well qualified holding a postgraduate or above degree.

3.2. Perception towards the use of IoT Technology

To gauge the understanding of IoT technology for climate action mitigation, the academic participants were asked questions about their familiarity with the concept of IoT and its effectiveness; and whether they are currently employing IoT in any of their climate related projects. The number of responses received are summarized in Table **2**.

Table 2: *Perception of academic participants towards IoT technology through number of responses received under each category.*

Education Level	Occupation			Familiarity with IoT Technology			Usage of IoT technology in climate related project			Effectiveness of IoT technology over conventional method		
	Faculty	Researcher	Student	Not sure	Somewhat familiar	Very familiar	No	Yes	To an extent	Conven-tional	IoT	Not sure
Postgraduate or above	76	10	7	9	36	48	49	12	32	1	80	12
Graduate	10	10	8	6	14	8	16	1	11	1	24	3
Under graduate	1	0	38	6	19	14	19	9	11	3	34	2

It is observed that most of the academic participants are fairly familiar with the IoT technology and believe it to be more beneficial than the conventional methods for climate change related projects. Despite this fact, most of them are not harnessing the benefits of IoT technology or involved in any climate change related projects. The figures in Table 2, point out the technology gap where the imbalance between the awareness of state-of-the-art technology and its utilization need to be diminished.

The IoT industrial consumers were also asked similar questions about implementing any IoT solutions in their industrial operations to address climate change related challenges. The responses received are recorded in Table 3. It is observed that the IoT customers are well equipped with the importance as well as the impact of IoT technology for tackling environmental challenges. However, the current use of IoT technology in industrial operations is observed to be still in infancy, and none of the industries are extensively employing IoT solution. Moreover, the readiness to IoT adoption in industrial sector is also scarce and the organizations are moderately ready to adopt and integrate IoT solutions into their businesses. In this aspect, the implicit fact based on the information provided is that the IoT technology and devices are widely available but their efficient utilization by its industrial consumers is not still fully realized. Moreover, the organization do not have much foresight as to how they ought to adapt in order to integrate IoT solutions in their processes and operations.

Table 3: *Perception of industrial consumers about IoT technology for climate related industrial operations through percentage of responses received under each category*

Familiarity with IoT technology		Current usage of IoT technology in industrial operations		Importance of data collected through IoT to understand environmental issues and plan mitigating actions		Readiness of the organization to adopt and integrate IoT solutions	
Somewhat familiar	Very familiar	Yes, to some extent	No, but plan for future	Very important	Neither agree or disagree	Moderately ready	Not ready
33.33%	66.67%	66.67%	33.3%	66.67%	33.3%	66.67%	33.3%

3.3. Technological attitude towards IoT for climate change

In this part of survey, we explore the academic stakeholders about their perceived benefits of IoT technology for climate change and the potential research areas for IoT technology and systems.

3.3.1. Potential benefits of integrating IoT technology

The academic participants were asked about the potential benefits of integrating IoT technology for climate change. The answers received are recorded in Figure 4. The primary benefit of embracing IoT technology is real-time monitoring and data collection. This allows prompt decision making based on current situations and optimized operational efficiency. Another benefit is enhanced predictive modeling and analysis. The IoT technology can provide real time insights into the condition and performance of machinery and equipment, consequently, any issue can be addressed before component failure. Additionally, by continuous monitoring resources can be managed efficiently and resource consumption can be optimized. IoT technology also facilitates remote monitoring and control. This is particularly useful in situations where huge physical infrastructure is impractical to deploy. IoT technology contributes to improved accuracy and reliability of data for a range of applications. Other potential benefits that have received little

attention are rescue and rehabilitation of areas that are badly affected by the disasters of climate change and prompt action through automated response to climate change.

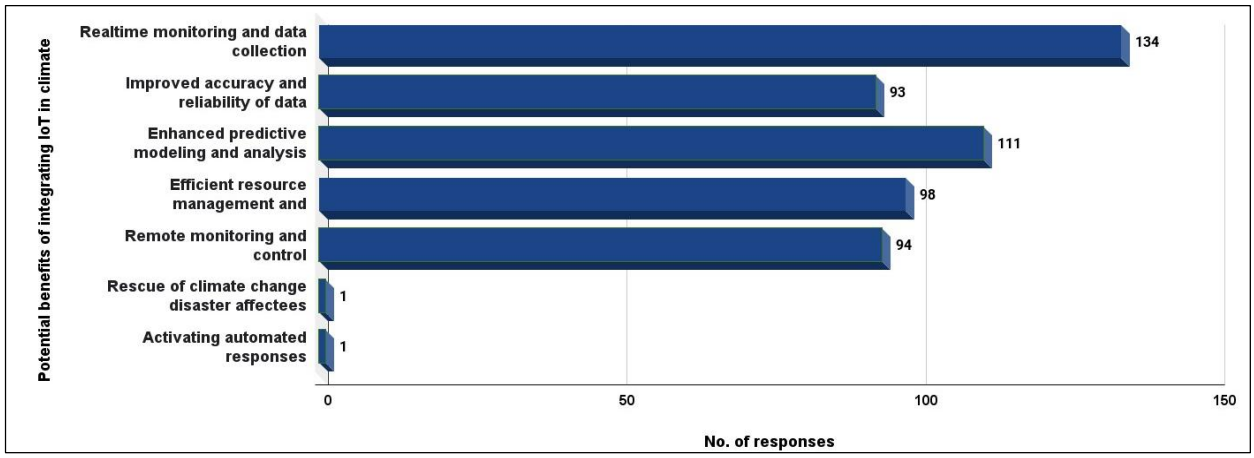


Figure 4: *Benefits of integrating IoT technology for climate change.*

3.3.2. Research and innovation areas in IoT technology addressing climate related projects

The academic respondents were asked to indicate their research areas for climate related projects reported in Figure 5. Major research work in Pakistan is focused on environmental or weather monitoring and data collection particularly air quality monitoring. Two other main research domains are water resource management and agriculture and forestry management. It has been estimated that by 2025, the global energy consumption of IoT edge devices will approach 46TWh [26]. As a result, energy efficiency is also main focus of all the researchers. Since IoT devices require continuous power, a sustainable solution to this challenge is utilizing renewable energy sources such as solar power. Other areas that are challenging and open for research community are infrastructure development, earthquake prediction and glacier melting due to climate change. To this end, the researchers are invited to initiate exploration of these areas and engage various stakeholders such as the government may develop thematic areas and IoT industry may start producing devices to work on these areas of climate change that have not yet received significant attention.

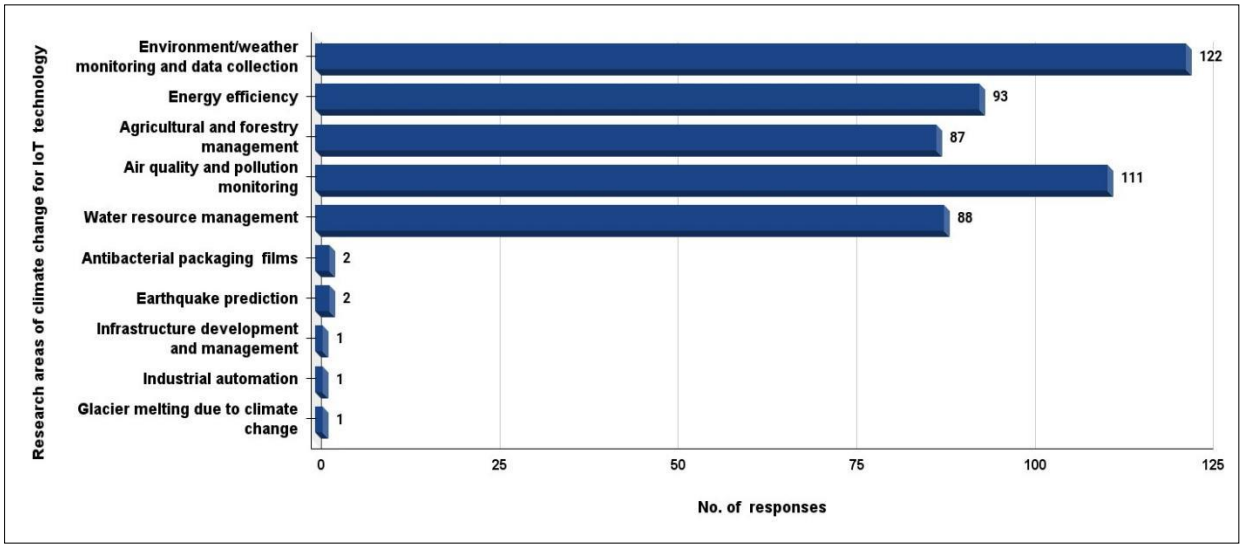


Figure 5: *Research areas of academic participants.*

The academic participants were asked to indicate potential areas for research and innovation in the field of IoT technology and devices to address climate change projects. Responses received are illustrated in

(a) Academic participants' perspective (b) Industrial consumer perspective

Figure 6(a). Majority participants believe integration of artificial intelligence (AI) and machine learning (ML) in IoT systems would be beneficial. The fusion of AI/ML and IoT are promising digital transformation technologies that envisions future in which a device learns, communicates, predicts and act autonomously. The potentials of automation and intelligence through the use of AI/ML is enabled by the edge and battery powered devices. Optimizing the power of devices is integral to reaching full benefits of IoT, therefore, development of low-power IoT devices is another research and innovation area. Some researchers indicated that IoT devices must be implemented to adapt strategies for climate change as well as enhanced analytics capabilities for climate modeling. This is particularly important for detection of environmental changes for early warning systems or emergency measures. Leveraging AI/ML and advanced data analytics can help to anticipate climate events and make proactive decisions related to climate change.

The industrial consumers were also inquired about the areas of the industrial sector where IoT technology can contribute most to combat climate change. The responses received are recorded

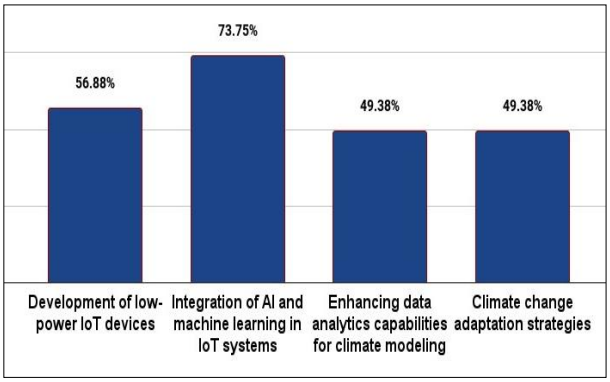
(a) Academic participants' perspective (b) Industrial consumer perspective

Figure 6(b). Similar to academic researchers, industrial customers indicate optimizing energy consumption to be the prime research and innovation area. The major energy consumption in IoT is due to computational overhead performed at sending nodes, and communication overhead in transmitting data from nodes to the server/cloud. For efficient resource utilization, this energy related issues must be addressed. Another envisioned innovative area is waste management, which promises a sustainable and green environment by reducing GHG emissions from different kinds of waste. IoT solutions are considered as crucial to circular system which aims to eliminate or handle waste generation through product reuse, redesign, recycle and refurbish material and regenerate nature. This could help societies to generate economic value and long-term benefits enabled through IoT. Equally, development of IoT systems to monitor and manage the resources (water, energy, solid waste) towards low CO_2 emission and achieving net zero energy [27]. Similarly, the advancement of IoT to extend product life by predictive maintenance, detecting faults and enhancing the useful life of equipment or proactively scheduling maintenance is an important innovation domain.

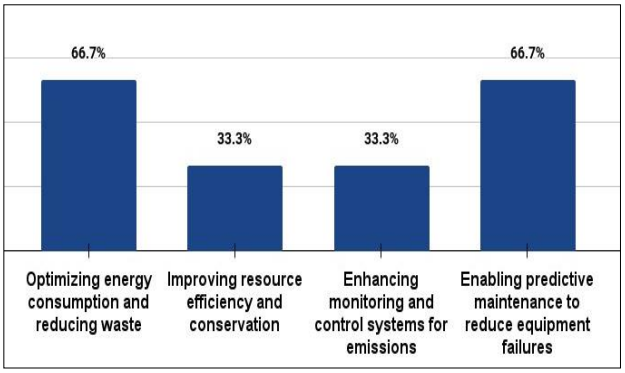
The industrial service providers were also questioned about the areas where their IoT devices have potentials for mitigating the effects of climate change. The main drivers of IoT technology in Pakistan are smart agriculture and farming solutions, smart energy management systems and sustainable transportation and logistics devices. The responses received establishes the strength of IoT devices and services thereby identifying effective value proposition.

3.3.3. Challenges/barriers in the adoption and deployment of IoT technology in climate change

Despite the innumerable potentials IoT technology has to offer, several limitations are also encountered in the wide scale deployment and adoption of IoT technology. In this section, we examine the major challenges anticipated by the stakeholders in the acceptance of IoT technology. The perspectives of academic participants are recorded in Figure 7. The biggest and obvious challenge of IoT is limited infrastructure and connectivity in remote regions and rural areas.



(a) Academic participants' perspective



(b) Industrial consumer perspective

Figure 6: *Research and innovation areas of climate change.*

Investment in broadband infrastructure can meet connectivity challenges and facilitate seamless adoption of IoT. Another challenge is the lack of awareness in end users. As commented by one of the respondents, *"The main issue is to convince the common people to use IoT Technology to combat the challenges posed by climate change".* Other technological challenges that have drawn considerable attention are data security and privacy, and ethical considerations related to data collection and usage responses. Another concern for adoption of IoT is the underlying heterogeneity of IoT prevents seamless integration and interoperability of different devices and systems. To ensure interoperability, there is a need for establishing set of standards, protocols and reference architecture for IoT protocols.

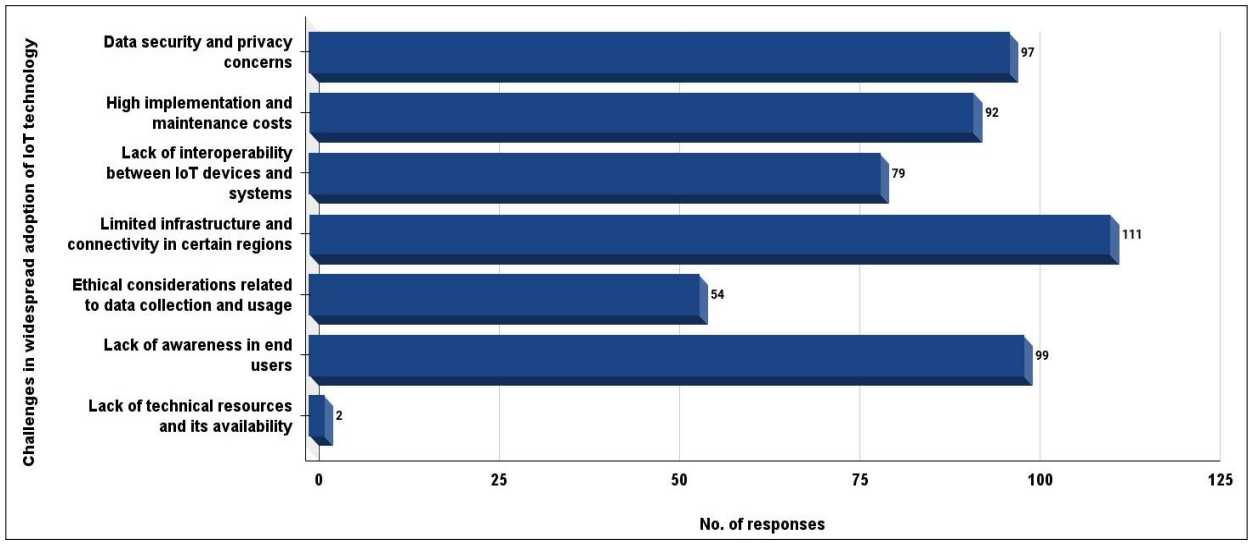
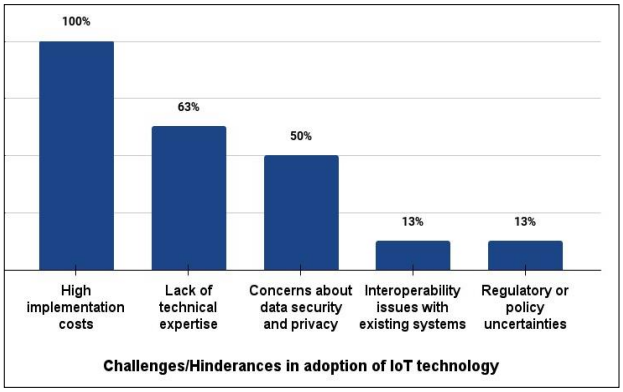
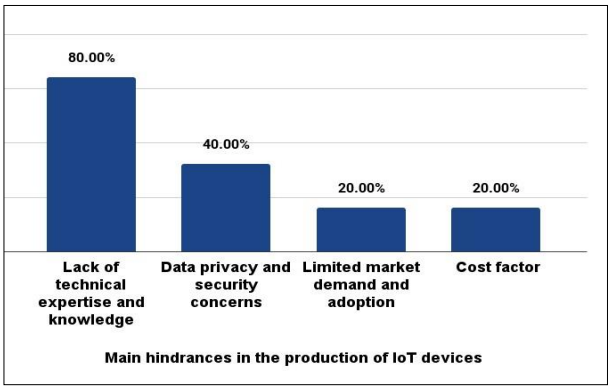


Figure 7: *Challenges encountered by academic participants.*

The industrial customers may also face several challenges by embracing IoT. It can be seen in **Error! Reference source not found.**(a), the topmost barrier faced by IoT business is high implementation cost as introducing new technology can be expensive. One of the factors that hinders IoT adoption is the lack of technical knowledge which may affect the decision-making ability about the available solutions of a particular problem. Since IoT connects different devices which stores sensitive data, security and privacy is also a major concern in businesses for wide scale deployment of IoT networks. Industries that uses IoT products and services have to process huge volume of data, therefore it is important to ensure interoperability of various devices so that the technology and solutions work well together. Moreover, there should be protocols ensuring data access, secrecy and privacy, absence of these causes barrier to widespread adoption of IoT technology.

From the perspective of IoT industrial service providers, the main hindrances in production of IoT devices for climate change mitigation are presented in **Error! Reference source not found.** (b). Majority companies find lack of technical expertise and knowledge to be a major factor that restrains manufacturing of IoT devices and growth of businesses. Enabling means to understand the IoT technology and educating the employees can help companies to reduce this digital divide. Many organizations also find difficult to trust technology and ensure confidentiality of information. IoT technology depends on a number of connected devices and users, the market size hence becomes crucial for IoT services to progress. Moreover, companies find lack of acceptance from end users to be challenging when they attempt to introduce innovative technological process.





(a) IoT customer perspective (b) IoT service provider perspective

Figure 8: *Barriers in the adoption of IoT technology in industry.*

The industrial service providers were also interrogated about the problems they face in remote monitoring of their services. Majority mentioned that they face connectivity challenges in remote areas. The inadequate infrastructure or limited access to technology in rural areas results in poor internet connection and cause difficulty in transferring data to and from IoT devices. Another challenge is the resistance from potential users, this is because the technology may not be perceived positively or its usefulness may not be easily acknowledged due to social norms and security as well as privacy concerns.

3.3.4. Features of IoT device/technology for climate related projects

The academic respondents of the survey were asked to specify the preference when selecting IoT devices or technology that best suits their climate related projects, responses are shown Figure 9. Cost-effectiveness is the fundamental selection criteria, since the cost of IoT devices vary depending upon functionality, project requirement and constraints. Reliability and durability of IoT devices is another key factor. The IoT devices must be able to withstand and perform accurately over temperature, humidity and pressure variations. For versatility, the choice of devices must also ensure seamless integration between IoT technology and existing system and infrastructure. There may be some projects where the devices need to operate for a longer period of time, or in remote locations where the charging may not be easily available, power efficiency and prolonged battery life in such cases becomes an important selection factor. Scalability of IoT network is also an essential feature that impact network performance since the system must ensure that it is able to handle growing number of devices generating huge volume of data.

The industrial service providers were also asked about the features they consider vital for an IoT device aimed at mitigating climate change effects. Responses received are reported in Figure 10. All industrialist agreed on real time data monitoring and analysis to be the major feature as this can provide timely and up-to-date data for analytics and intelligent decision making. Predictive insight and forecasting ability is another desirable feature that allows to identify trends and detect anomalies in real-time data streams. Moreover, relevant actions may also be triggered to mitigate and prevent potential problems. Industrial service provider also prompted that integration with renewable sources, energy efficiency and optimization is also beneficial. This is particularly important in remote areas with limited access to reliable power sources. Lastly, enhanced connectivity and interoperability features can benefit where a number of devices need to be connected and huge amount of data need to be transmitted or processed.

3.4. Stakeholder involvement and resource management to address climate change

3.4.1. Resources and support mechanism

The survey asked participants to highlight the resources and support required for the enhancement of IoT technology for initiating their climate related projects, the answers received are shown in Figure 11. To avail the maximum benefits of the technology within their working projects, majority of the participants aspired to have funding and grants from government or private sector. Many participants have also shown interest for training and professional development programs as well as technical support or consultation services. Obtaining hands-on training and support on IoT technology delivered by professionals having extensive market experience, would enhance the expertise of academia who have profound theoretical background. Consequently, the IoT projects

would be delivered up to market-centric expectations. Another dimension to foster IoT technology is collaborations or growing networks for knowledge sharing. By working together, the academia, service providers, businesses and start-ups can create an ecosystem that has capacity to deliver efficient and innovative products/solutions/services.

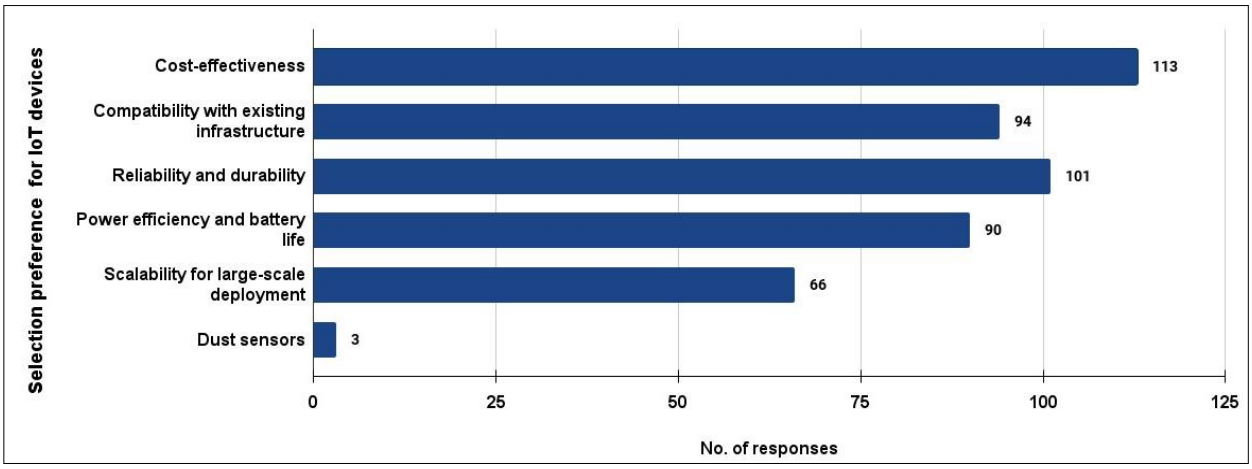


Figure 9: *Preference when selecting IoT devices/technology for climate related projects.*

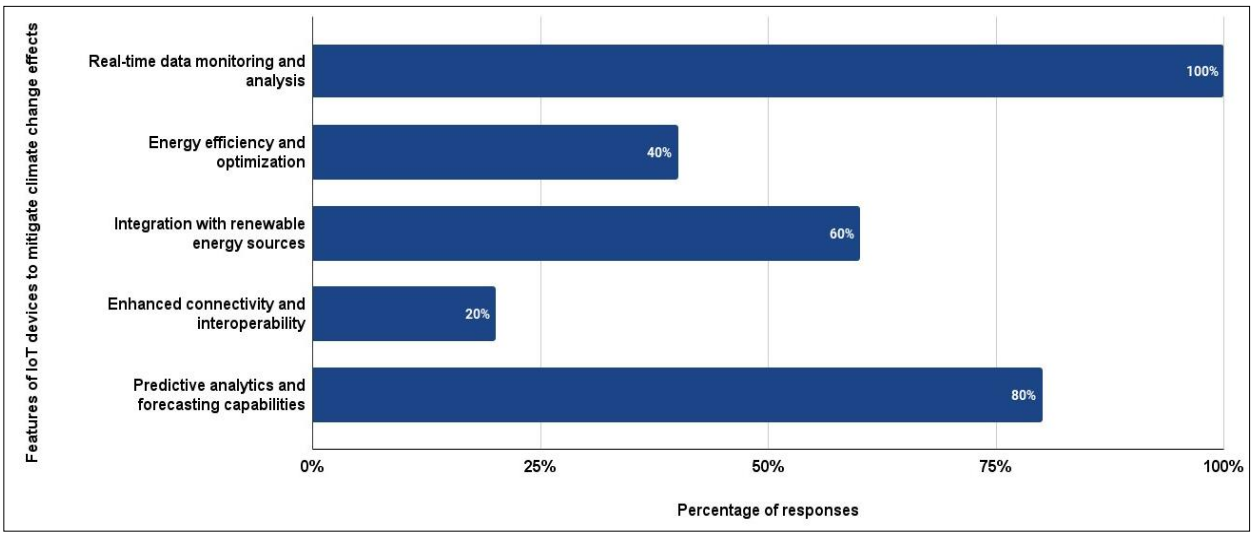


Figure 10: *Features of IoT devices/technology for climate related projects-service providers' perspective.*

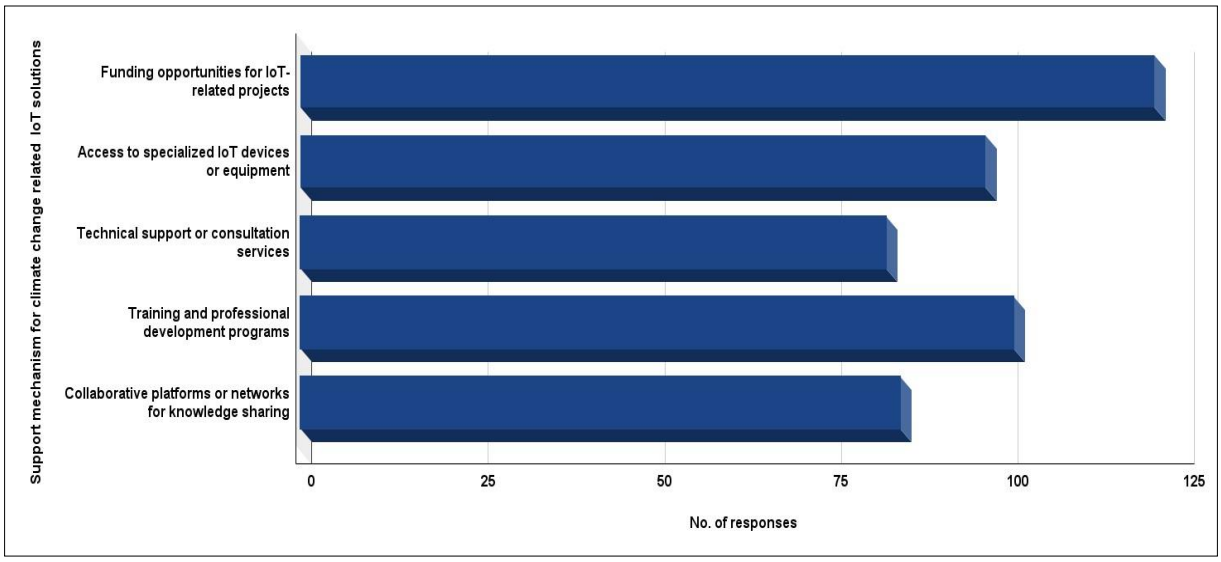


Figure 11: *Beneficial resources in integrating IoT technology for climate change.*

3.4.2. Interoperability, scalability and adaptability among IoT devices

The IoT technology has revolutionize businesses and the organizations have seen opportunities to develop services and solutions, targeting customers and other related companies. However, there may be cases where similar technical solutions are deployed to customers in same location, by different service providers each having their dedicated infrastructure. This disintegration leads to interoperability and scalability issues when multitude complex solutions need to be delivered. To explore the drivers for this disintegration, the industrial service providers were asked about the importance of their IoT devices to be scalable and adaptable to different industries and sectors as well as existing infrastructure. While industrial customers believe that it is important for IoT-based climate change solutions to be interoperable, most of the IoT service providers responded, *"it is not important at all"*. The possible reasons may perhaps be the customer attrition, hesitant to change their existing model, strategy and framework or share their data with other businesses, and lack of trust for collaborative platform. End users prefer the convenience to use IoT technology and devices relevant to their specific application and needs, irrespective of the service providers. Therefore, for enhanced customer experience, it is important to understand the need for enabling interoperability among devices.

Moreover, the dedicated infrastructure of each IoT service provider has specific data formats or application programming interfaces which leads to interoperability and openness issues. To resolve this vertical silos, there must be a unified communication model to address heterogeneity of devices and enable cross-platform applications through seamless integration of new devices in IoT network and applications [28]. Furthermore, to facilitate interoperability, the resource sharing among various service providers must be encouraged. This requires efforts at various levels from IoT vendors, academia as well as standardization/regulatory bodies.

IoT technology envisions a complex system with large number of devices, variability of applications and dynamic environment surrounding IoT systems. These factors necessitate the need for adaptability in the network for increased efficiency and robustness to changes in the environment. The infrastructure must be scalable to accommodate growth and expansion of users and computational resources. There must be thorough evaluation of existing state-of-the-art IoT

infrastructure and framework adopted by different organizations to formulate the scalability requirements.

3.4.3. Role of collaborations

For an evolving ecosystem, the industry-academia collaboration plays an instrumental role. The majority of participants strongly believed that industry and academia should work in collaboration to further the advancements of IoT technology. Academic research is helpful for organizations to attain a competitive insight to develop new designs and solutions.

As realized by majority industrial participants, there is also a need for building partnerships between private and local/regional government organizations to advance IoT technology to address climate change issues. Our survey indicates that some private companies are proactively collaborating with municipal government for smart initiatives related to climate change. This not also helps public sector to utilize efficient IoT services of private sector, but also benefits both through sustainable investment opportunities as well as economic growth [29].

In addition, the industrial symposiums, conferences and seminars are specialized professional events that allows companies to collaborate at different levels, provides comprehensive knowledge about latest trends in technology and development in industry. The companies can interact with peers and customers to network and discuss strategies for the growth of their businesses. Undoubtedly, most of the industrial participants find it is important to actively participate in conferences, seminars, or workshops focused on IoT solutions for climate change. They were also keen to invest in research and development efforts by academia to create innovative IoT devices specifically designed for climate change mitigation.

3.4.4. Customer feedback and large-scale pilots

When developing product and services, it is imperative to consider customer-centric approach so that it fits the users' demands. For increased level of acceptance and adoption of IoT technology, large-scale pilots are conducted to understand users' motivation to adopt IoT technology and to get insights of users' experience about the technology. Pilots provide an opportunity to IoT developer to design, test and implement their innovative IoT solutions [30]. The industrial service providers were asked if they had ever considered conducting pilot tests or trials of their IoT device in collaboration with potential end-users to gather feedback and improve its functionality. Most of them have shown positive response to substantial user engagement. This finding is essential to understand the gap between factors affecting the customer adoption of IoT technology and the challenges within pilot process that hinders widespread adoption.

3.4.5. Role of Government policies

In this part of the survey we aimed to identify the role of government in devising policies for standardization and interoperability of IoT devices. Since climate change mitigation policies require not only involvement of technical experts, but also focus on citizens' engagement for normative perception [31], [32]. Therefore, the survey participants were asked about their engagement with policymakers and regulatory bodies to encourage the development of IoT for climate change through policies and regulations. 65.3% participants agreed on having policies defined by government, whereas 27.4% were not sure about the role of government. Few respondents i.e. 7.3% rejected the idea of having governmental policies for IoT technology. When asked about the support from governmental bodies or other organizations, mixed responses were received which includes *"no"* and "*prefer not to disclose"*.

4. Recommendations

The analysis in section 3 exhibits that there is a need for strategic planning and policy making to develop a unified framework among stakeholders on a societal level. In the following subsections, we present some recommendations and suggested actions that may be adopted at different levels for promoting usage of IoT to address climate change.

4.1. Capacity building on IoT and climate change

The first step in mitigating the challenges posed by climate change is to spread awareness about the threats of climate change and its effects on health. This will inculcate national ownership and nurture behavioral change of a community by practicing actions needed to combat climate change and reduce emissions. The dissemination of information related to climate and health, can be achieved through a wide range of activities that includes promotion campaigns and multimedia broadcasting addressing general public as well as policy makers. The advertising material may mention health risks associated with climate change, set of guidance tools and policy briefs. Moreover, to facilitate capacity building, trainings, seminars and engagement forums for climate related agenda must be held frequently to raise prominence of climate resilience and sustainable response. Similarly, integrating IoT into climate change context is an emergent process and low level of awareness still exists on the subject. Therefore, it is vital to create digital literacy skills about IoT among general public and rural community. By appropriately educating the end users and creating awareness about the potentials of IoT technology, the barriers to adoption and acceptance can also be resolved.

4.2. Climate finance opportunities for IoT projects

To support developing communities to cope with the climate change and its effects on livelihoods, climate funds are provided by international and non-governmental organizations. This provides financial empowerment to vulnerable and poor countries by providing grants and funding to implement climate resilient projects [33], [34]. Green finance is another extensive contributor to supporting sustainable environment projects such as optimized energy utilization through the use of renewable energy sources, managing air pollution, and climate change mitigation. These green initiatives improve environmental quality, enhance economic growth and develop sustainable livelihood [35]. In this regard, the government of Pakistan needs to accelerate efforts to acquire global climate finance for environmental protection as well as technology development. Meanwhile, the funding opportunities for building startup ecosystem are accelerating [36],the government should take measures to invest more in research projects on IoT for climate change that can be transformed into startups. Correspondingly, the government must also introduce subsidize programme for development of IoT technology in educational institutions for carrying out research projects related to climate change.

4.3. Standard, policies and regulations for IoT

To facilitate IoT ecosystem in Pakistan, the Pakistan Telecommunications Authority (PTA) has introduced a set of regulatory framework for the services and operations[37]. But given the relatively recent formalization of regulations and strategic decision for innovative IoT, more guidelines need to be set for promoting industry-wide IoT interoperability standards. Currently, in the IoT standards, there is no accepted terms for representing IoT data and semantics [38]. In the absence of standards and specifications, it is not possible to develop interoperable IoT endpoints that adhere to a common information or communication model. Therefore, there is a need for a policy about how to manage and analyse the data. Moreover, another important requirement is to provide robust and scalable solutions for the discovery of devices and their configuration. There is also a need of developing regulations for handling security and privacy of personal data which

can become vulnerable to security threat. This requires coordination between IoT service providers, telecom operators, regulatory bodies and other parties involved for defining rules governing the collection, use, protection and disclosure of personal data.

4.4. Collaborations and partnerships for climate change mitigation

To formulate successful deployment of IoT technology for solving the local and global challenge caused by climate change, the triple helix innovation model can be followed. This involves aligning and actively engaging all the stakeholders and experts from academic and research community, policy makers, strategic organizations and public and private sector, IoT technology service providers, network operators, non-governmental organizations and distinguished members of civil society. Through an integrated approach all dimensions including technical, economy, legal, social and environmental, could be visited in a sustainable manner.

At national level, collaboration with relevant partners, such as the Meteorological Department, Ministry of Agricultural Research Council, and, The Ministry of Climate change and Environmental Coordination, is vital for strengthening capacity on climate change as well as to enhance the climate change mitigation and adaptation initiatives of respective department. At the same time, public-private partnership can advance the actions related to climate change. Many companies and businesses support or provide funding to innovative environmental projects that align with their corporate social responsibility objectives. In addition, industry-academia linkage could drive the research outcomes to next stage for innovation and commercialization. This leads to job creation, manufacturing of value-added-products customized for the local environment and progressing industrialization. In this regard, a viable platform needs to be created that could connect innovative minds to the industrial partners for commercializing the prototypes of the IoT based solutions for climate change. Universities can effectively utilize the role of their technology transfer offices to attain outcome such as patent, licensing, sponsored research and university spin-offs.

4.5. Open research challenges for academia and researchers

Driven by their complementary features and properties, a major research areas is integrating IoT with cloud computing technology, generally known as CloudIoT [39]. However, the complex CloudIoT faces several challenges open for research community including lack of standardization, security and privacy, interoperability due to non-heterogeneity of devices, interfaces and operating system, and energy efficiency. Many researchers have integrated metadata with IoT solutions, for efficiently managing and interpreting data generated by IoT devices [40], as well as maintaining dynamic interoperability [40], [41]. In addition, metadata also ensure authorization and authentication of each device connected on the network. Hence, it is recommended to use metadata in IoT ecosystem for resolving compatibility issues, and accurately interpreting sensor's data. Moreover, metadata enabled IoT systems provides quality of the data context, which facilitates data-driven analysis and decision making through the use of AI/ML algorithms. Currently, IoT standards for metadata are inadequate, with little or no provisioning of metadata in the life cycle of an IoT devices [38], this area needs to be explored further. For ensuring data security and privacy, robust encryption algorithms are needed. Many IoT devices are not computational or power efficient, therefore energy efficient and light weight key distribution schemes need to be developed for IoT devices [42].

4.6. Recommendations for IoT industry and service providers

The industry must focus on developing low cost and high precision sensors in specific vulnerable areas (e.g. environment, agriculture, water resources, infrastructure) that are worsened by the

impacts of climate change. AI empowered IoT systems are power inefficient and time-consuming in design. Hence there is a need for manufacturing power optimized and energy resource constraint sensors as well as infrastructure/hardware. However, the challenges that need to be confronted will be cost of initial investment, maintenance and operational cost. To support interoperability, the IoT service providers are recommended to use open standards and platforms as well as follow modular approach for designing IoT solutions that could facilitate integration with other system. It is also suggested that prior to investing in full-scale deployment, a prototype or a small-scale pilot of the IoT solution must be developed to validate the design and identify potential problems. The solution may then be expanded taking feedbacks from other stakeholders and consumer experience. It is also vital to ensure appropriate security measures for data protection in all the IoT solutions.

4.7. Recommendations for Government and regulatory bodies

The government must provide awareness on climate change policies and initiatives. Investment in development of IoT infrastructure for climate related projects, policy reforms, and capacity building such as mentorship, training, and networking are essential for IoT adoption and growth.

During interaction with IoT startups and service providers, some of the areas of difficulty were the lack of government regulatory support, unawareness of policies and unfavourable sales tax system. As a supportive measure, some tax incentives should be offered to service providers and consumers so as to attract investment in IoT technology for climate change and to enable a conducive and encouraging IoT eco-system for companies. Moreover, due to inconsistent sales tax regime charged on companies for the import of IoT equipment, the cost of services for end users increases. The government should reduce this sales tax on IoT companies and ICT related services.

5. Conclusion

The main objective of this regional study was to explore the ways in which IoT could be integrated into climate change mitigation and adaptation policies in Pakistan by means of understanding the stakeholders' awareness and expectation. Study of this nature has yet not been conducted in Pakistan and through this survey, stakeholders demonstrated awareness of the importance and benefits of IoT technology for climate change mitigation. The results from the analysis suggest that efforts have been initialized by the industrial stakeholders and academic institutions to integrate IoT into climate change adaptation and mitigation. The national climate change policy is established and determining course of action of the Government to practice realistic and viable and efficient strategies to address climate related challenges. However, promoting development and diffusion of IoT technology for climate change still require consideration in terms of standardization and regulatory policy. The lack of regulations to provide security and privacy of data, IoT data management and interoperability issues within the IoT systems are still some of the challenges identified in this study.

Data Availability: The analysis of data generated during the current study is presented within the text and the survey forms are submitted as a supplementary material.

Statements and Declarations

Competing Interests: The authors have no competing interests to declare that are relevant to the content of this article.

Ethical Declarations: The authors declare that the research has been conducted ethically without collecting any personal information, keeping in mind privacy and consent of those involved in the study.

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