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ENABLING TECHNOLOGIES CHALLENGES OF GREEN INTERNET OF THINGS (IOT) TOWARDS SUSTAINABLE DEVELOPMENT IN THE ERA OF INDUSTRY 4.0

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Abstract. The extensive adoption of the Internet of Things (IoT) has increased the carbon footprint on a large scale across the globe. To handle this challenge, scholars and policymakers are making efforts to propose novel energy-efficient solutions to provide a desirable environment for green-IoT (G-IoT). Additionally, further research is required to analyze the G-IoT-related challenges to elucidate the difficulties of its implementation for researchers. Moreover, the G-IoT requirements have been considered in different network levels, namely software, hardware, architecture, communication. To present a comprehensive framework to identify the challenges of G-IoT, a survey using literature review and expert's opinion is carried. Total 23 challenges are taken to evaluate and implement G-IoT technologies towards sustainable development achievements (SDA). Consequently, this article aims to rank and evaluate the challenges to implement the G-IoT towards the SDA. An integrated approach is proposed with stepwise weight assessment ratio analysis (SWARA) and additive ratio assessment (ARAS) under Pythagorean fuzzy sets. As a result, an machine-to-machine (M2M) standardization protocol with a weight value of 0.0508 has the first rank, followed by adaptation to natural energy sources with a weight value of 0.0479, information security and privacy protection with a weight value of 0.0469, and internet protocol version-6 (IPv6) for low-end devices with weight 0.0467. To validate the proposed method, sensitivity analysis and comparison using existing methods have been conducted.

Keywords: green internet of things, sustainable development, energy consumption, Pythagorean fuzzy sets, Industry 4.0, digital technologies, additive ratio assessment.

JEL Classification: O32, O36.

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Introduction

The world is experiencing a continual rise in energy demand, mostly because of population growth and the emergence of novel services (Varjovi & Babaie, 2020). Statistics show that the world population can increase to 9 billion by 2050, which can increase worldwide energy consumption by roughly 50% in the same period (Boretti & Rosa, 2019). In addition, a critical concern is that the majority of industrial applications are dependent upon fossil fuels, which has resulted in a significant increase in emissions of Carbon dioxide (CO_2) and greenhouse gas (GHG) (Varjovi & Babaie, 2020). The increase of GHG emissions has caused the rise of climatic temperature, and scientists have urged the exploration of energy management strategies with higher efficiency and also technologies of higher sustainability (Masnadi et al., 2015). Green energy obtainable from wind, solar, biomass, and geothermal sources is a proper form of energy that can be used instead of conventional energy (Yanık et al., 2016). To moderate the role of fossil fuels in daily life, recent years have experienced a considerable inclination to use renewable forms of energy in different areas like generating and distributing power, producing fuel, and supplying the energy required in different sectors (Abokersh et al., 2017). Such types of energy can enhance the quality of people's lives, improve their health, and, at the same time, exert less adverse impacts on the environment. Generally, energy saving is a great objective that could be accomplished well by improving the energy efficiency of the production procedures and implementing energy-efficient systems for monitoring and managing purposes (Zhu et al., 2011).

Information and communications technology (ICT) systems and products require great energy resources to be well manufactured and distributed. This causes a considerable increase in energy demand and great growth in the volume of different forms of waste, which all negatively affect people's environment and health status (Maksimovic, 2018). These problems place a great challenge to the sustainability of economic developments and the living place's sustainability (Vidas-Bubanja, 2014). As a result, green ICT can provide a greener future for human beings, in which individuals have higher awareness regarding the effects of technology upon their health and environment. Despite such great advantages, many obstacles still exist to introducing, developing, and implementing green technologies, e.g., commercial barriers, technical barriers, and regulatory barriers (Maksimovic, 2018). The fast development and implementation of ICTs have directly and dramatically affected all aspects of human beings' lives and have transformed an "industrial" society into a global "information"-based one.

As an innovative ICT solution, the internet of things (IoT) significantly changes the way people interact with each other, organize their lives, and participate in different domains of society (Dantu et al., 2021; Lei et al., 2021). Essentially, IoT is a universal network of intercommunicating physical "things", which provides a worldwide interconnection among people and things anytime and anywhere. It can considerably reform people's lives and businesses (Aswale et al., 2019; Rachedi et al., 2016). Therefore, with the help of the Internet, IoT, and mobile technology, a wide connection is established among individuals, organizations, places, and facilities (Maksimovic, 2018). Technology growth has offered numerous benefits and brought "smartness" to various aspects of human life; on the other hand, their fast development has caused more waste generation, the increase of GHG emissions, and the consumption of natural and non-renewable raw materials.

As IoT involves too many things and objects, even a small decrease in the amount of energy consumed by each network element may significantly reduce the total amount of energy consumed by the entire network (Varjovi & Babaie, 2020). Moreover, the data produced by this technology (which is recognized as big data) are stored on servers whose effective energy management can lead to the achievement of an energy-efficient network. Taking into account the environmental effects from the beginning of a process and involving such effects in the development and application of IoT can result in the growth of green IoT (G-IoT), which can remarkably improve the humans' health state and develop the economic system of the world (Yang et al., 2020; Zhang et al., 2020). Although G-IoT is still in its infancy stage, it is considerably energy-efficient and effective in reducing pollutions (especially carbon emissions) and strengthening the sustainability of environmental/economic settings (Batra et al., 2020; Dai & Lyu, 2020). Thus, firms, organizations, and people are engaged in IoT innovations to develop green and sustainable services/products and explore more room for promoting the G-IoT business at a global level (Maksimovic & Gavrilovic, 2016). Similarly, as IoT elements normally have communicated with each other through wireless channels, green wireless communications can greatly affect the achievement of an energy-efficient IoT (Liu & Ansari, 2019). In general, concentrating upon energy efficiency in G-IoT can significantly decrease the GHG emitted by IoT-related technologies and increase the acceptance of this technology (Zhu et al., 2015).

With considering the principles, ideas, and probable advantages of G-IoT, the effects of G-IoT on the most important sectors in the green economy have been comprehensively analyzed (Raut & Dhanya, 2020). With the implementation of G-IoT, we can develop services/products with the least or no influence on human health and no damage to the environment; it could also minimize the amounts of energy consumed in the production processes and many types of pollution. This way, the world could be a place of higher environmentally-awareness and appropriateness for life. As a result, G-IoT and many other smart systems are capable of providing social development with a high degree of sustainability.

IoT involves many different objects that are indispensable to human life; as a result, energy efficiency can be considered an essential requirement for IoT (Varjovi & Babaie, 2020). Generally, if IoT considers the issues related to energy efficiency, the result could be G-IoT (Zhukovskiy et al., 2019) that can reduce the costs and, at the same time, decrease the risks people's health. Due to the high importance of environment conservation, several business platforms and models have been proposed by several active IT firms worldwide. Furthermore, more research is required to open G-IoT issues such as technical challenges, standardizations, innovation, security, etc. Thus, there is a need for efficient policies to be established for developing G-IoT through addressing the prominent challenges and articulating the most proper standards. Furthermore, the literature shows that the green objectives must be addressed in G-IoT's general cycle, which includes designing, producing, utilizing, and finally disposing of the products or recycling them (Varjovi & Babaie, 2020).

The intuitionistic fuzzy sets (IFSs) theory was developed by Atanassov (1986). This theory essentially involves two concepts: belongingness grade (BG) and non-belongingness grade (NG). It holds the constraints that the addition of the NG and BG is equal to or less than 1. On the other hand, in some conditions that might arise when a decision is being made, the decision experts (DEs) may give the grade of 0.8 once an option meets the criterion or 0.5 in case the option does not satisfy the attribute. In such a situation as $0.8 + 0.5 > 1$, the IFS cannot handle this situation (Yager, 2014). To cope with this challenge, Yager (2013) and Yager (2014) pioneered the notion of Pythagorean fuzzy sets (PFSs) that is capable of satisfying the constraint in which the square sum of ND and BD is equal to or less than 1. As a result, PFSs outperform IFSs in terms of defining the nature of ambiguity. Due to their exclusive benefits, Zhang and Xu (2014) and Peng and Yang (2015) used the operations of

PFSs to find acceptable solutions to group decision-making. Zeng (2017) carried out a study into various aggregation operators, as well as a MCDM procedure for PFSs. Ak and Gul (2019) made use of an analytic hierarchy process (AHP)-technique for order preference by similarity to ideal solution (TOPSIS) method for PFSs. In another study, Liu et al. (2021) discussed and prioritized the medical waste treatment technologies with combined compromise solution (CoCoSo) model for PFSs. Rani et al. (2021) developed a combined framework to PFSs and the weighted discrimination-based approximation (WDBA) model.

Through the procedure of multi-criteria decision-making (MCDM), DEs provide a high significance to the weight of each criterion available. The stepwise weight assessment ratio analysis (SWARA) approach was presented by Kersuliene et al. (2010) for the purpose of calculating the subjective weights. By comparing with different tools, namely the AHP, it can be said that the computations in SWARA are simple. The SWARA method is an effective way to compute the criteria weights. Mardani et al. (2020) introduced a combined structure on the basis of various approaches with hesitant fuzzy sets (HFS) with the aim of evaluating the digital health intervention for the duration of the COVID-19 pandemic. Cui et al. (2021) gave an extended Pythagorean SWARA-CoCoSo model in the circular economy context. Recently, various other researchers have concentrated on the SWARA model in different environments (Puška et al., 2019; He et al., 2021; Alrasheedi et al., 2021; Saraji et al., 2021; Vrtagić et al., 2021).

During the past few decades, MCDM was considered a key process of people's daily lives. In realistic circumstances, it is not easy to solve MCDM problems (Cavallaro, 2010). Because of the increasing complexity and widespread alterations to today's environments, the conventional MCDM methods are generally inapplicable to the MCDM problems. Zavadskas and Turkis (2010) pioneered the additive ratio assessment (ARAS) model, indicating that the events of this intricate world may be implicit using easy relative comparisons. ARAS makes use of the concept of an optimality degree in order to achieve prioritization. The most important benefits of ARAS include: 1) direct and proportional relationship with attribute weights (Iordache et al., 2019), 2) having the ability to solve complicated problems (Büyüközkan & Güler, 2020), 3) involving some simple and direct steps for the assessment of a number of options or choices based on their performance in comparison with the chosen evaluation criteria that obtained suitable, sensible, and comparatively-accurate results (Zavadskas & Turskis, 2010; Turskis & Zavadskas, 2010a). Most situations where the conventional ARAS has been recently utilized have been aimed at personnel evaluation purposes (Karabasevic et al., 2016), the ranking of firms on the basis of indicators of corporate social accountability (Karabasevic et al., 2016). In recent years, this approach has been elaborated in various uncertain fields. A popular instance is the ARAS Grey model (Turskis & Zavadskas, 2010b), which was extended on interval-valued triangular fuzzy numbers (Stanujkic, 2015). Mishra et al. (2021) suggested an integrated ARAS method to evaluate and prioritize the electric vehicle charging station locations.

G-IoT technology is addressed in the present study because of its certain characteristics like enhanced energy efficiency, eco-friendliness, and quick development in different applications. On the other hand, the G-IoT challenges are also examined with the aim of elaborating its problems for scholars working in this area of study. Furthermore, the G-IoT green requirements are investigated at various network levels such as software, hardware, architecture, and communication. Therefore, this paper aims to identify, rank, analyze, and evaluate the various challenges that may appear in the process of implementing G-IoT for achieving sustainable developments using an integrated SWARA-ARAS method under PFSs. To present a comprehensive framework to identify the important challenges to implement the G-IoT, a survey study using literature review and expert's opinion is carried. The result of the survey approach indicated that, in total, 23 challenges were important to evaluate and implement G-IoT technologies for development with a high level of sustainability. Consequently, the main objectives and contributions of the manuscript are as follows:

- To conduct a survey approach using expert interviews and literature review to identify the main challenges to implement G-IoT technologies for development with a high level of sustainability.
- To propose an integrated decision-making method with the SWARA-ARAS method and PFSs to the evaluation of the main challenges to implement G-IoT technologies for development with a high level of sustainability with an integrated decision-making approach.
- To apply the SWARA method under PFSs to rank and analyze the main challenges to implement G-IoT technologies for development with a high level of sustainability.
- To use the ARAS model on PFSs to rank the organizations with respect to the various challenges to implement G-IoT technologies for development with a high level of sustainability.
- To discuss the comparison and validation of the proposed PF-SWARA-ARAS method with the extant decision-making approaches.

The organization of the paper is managed as follows: Section 1 presented the literature review and challenges evaluation. Section 2 presented the research method and basic information of the proposed method and proposed an integrated decision-making approach under Pythagorean fuzzy sets. Section 3 discussed the results, sensitivity investigation, and the comparison method. The last Section discussed the conclusion, limitations, and future recommendations for future works.

1. Overview of Green IoT

IoT refers to a global, ambient, immersive, invisible network of communication and environment of computation, which is essentially constructed on the basis of using smart sensors, cameras, software, databases, and data centers within an information fabric system at a worldwide scale (Alsamhi et al., 2019; Doknić, 2014). Wang (2014) used the concept of IoT to build a green campus environment to save as much energy as possible. In spite of the evidence provided in (Wang, 2014), different elements of IoT were discussed (Gubbi et al., 2013). They also described the benefits of the IoT architecture regarding how we can build a green campus using progressive technologies smartly and efficiently. In Prasad et al. (2010), certain technical directions were addressed to realize the future green internet. Innovative technologies and revolutionary movements induced by IoT in many aspects of human life have provided great access to information in new ways; it also has unified people, processes, things, data, organizations, places, and facilities in an extraordinary way (Maksimovic, 2018). Even though IoT has offered many benefits, the processes of manufacturing, distributing, and using this technology are resource and energy intensive and arise mounting mass of solid and toxic wastes. For the minimization of adverse impacts of development upon people's lives and environment, there is a need for appropriately addressing the challenges like the increasing rates of energy consumption, GHG emissions, waste generation, and the natural materials consumption.

The above-noted challenges are driving the practitioners and academic community to make their best to move toward a greener future in which IoT, technology, and economy could be as green as possible. It could ultimately result in the enhancement of human well-being, thereby contributing to the creation of the smart world of high sustainability. The leveraging element of IoT is the reduction or elimination of CO_2 emissions, reducing pollutants, and improving energy efficiency. Uddin and Rahman (2012) proposed a number of techniques to improve energy efficiency and decrease CO_2 to enable G-IoT. As a result, IoT and ICT could be taken into account to address environment-related issues well. Green ICT, in fact, attempts to model, develop, use, and dispose of computers, servers, as well as accompanying subsystems responsibly (from an economic perspective). It also applies dematerialization processes with enhanced energy proficiency and minimized waste generation rate, poses negligible or no effect upon the environment and people's health, and improves ICTs recycling processes. Thus, green ICT can provide maximum benefit and, simultaneously, minimum damage. The process of greening ICT involves greening the communication and computing technology and also the use of smart grids and applications (Ozturk et al., 2011). A key challenge is how to deploy green communication and system models in IoT since a substantial amount of energy is consumed for establishing the required communications and, on the other hand, the IoT devices are normally limited in their energy sources (Abedin et al., 2015). Therefore, the key objective of green communication technology is how to reduce the rate of energy consumption and CO_2 emitted by communication and networking devices. In addition, some activities such as providing online collaboration settings through virtual meetings, teleconferencing, and participating from home can greatly affect saving costs, facilitation of management procedures, and reducing the amount of energy consumed. In the field of green communication technology, the most important research areas include green wireless communication, energy-efficient packet forwarding, evolving communications architectures, relay selection strategies for green communication, networking games, energy-efficient routing, etc.

G-IoT is mainly concentrated upon reducing the energy consumption of IoT, which is considered an imperative measure to fulfill the smart world with the sustainability of intelligent everything and reducing CO_2 emissions. G-IoT also involves a number of designing and leveraging aspects. In the context of networking, G-IoT aims to identify the location of the relay and the number of nodes that can meet the energy-saving and budget constraints. In the process of realizing a world of both smartness and sustainability, G-IoT deploys IoT in a way to decrease the energy consumption rates (Maitra et al., 2020), CO_2 emission (Salam, 2020), and pollution (Jiyal & Saini, 2020; Senthilkumar et al., 2020), exploit environmental conservation (Maceli, 2020), and minimizing power consumption (Serra et al., 2020). Murugesan (2008) also defined the green IoT 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." Three different concepts are included in G-IoT: design technologies, leverage technologies, and enabling technologies. Design technologies are referred to as the devices' energy efficiency, communication protocols, network architectures, and interconnections. Leverage technologies refer to the elimination of carbon emissions and the improvement of energy efficiency. Because of the green ICT technologies, G-IoT has become more effective by reducing energy consumption, decreasing dangerous emissions, reducing resource consumption, and alleviating pollution. As a result, G-IoT contributes significantly to preserving natural resources, minimizing the technology effects upon the environment and human health, and reducing costs. Thus, G-IoT is mainly concentrated upon green design, green manufacturing, green utilization, and finally, green disposal (Nandyala & Kim, 2016).

Accordingly, G-IoT can substantially change human beings' future lives and provide a green environment. In the future, we can expect to see many machines, devices, drones, sensors, and things in close communication with each other to accomplish the defined tasks in an intelligent way to provide a green environment. G-IoT helps other industries not only to alleviate GHG impacts but also to minimize the impacts of IoT itself upon the environment. G-IoT indeed helps IoT explore a variety of eco-friendly energy sources and lower the IoT-induced risks to the environment. Consequently, G-IoT significantly contributes to the economy, environment, and society in a highly sustainable way, preserves natural resources, and improves people's health. G-IoT changes our future environment to be healthier and greener with high levels of quality of service (QoS). Today, there are many areas of study that are focused on greening concerns, e.g., green communication and networking (Niu, 2020), green design and implementations (Janhunen et al., 2019), green IoT services and applications (Abedin et al., 2015), energy-saving strategies (Arshad et al., 2017), integrated Radio-frequency identification (RFID) and sensor networks (Alsharif et al., 2019), mobility and network management (Said et al., 2020), the cooperation of homogeneous and heterogeneous networks (Hu & Qian, 2014), smart objects (Sukjaimuk et al., 2018), and green localization (Liu & Ansari, 2019).

The question of how to deploy green technology has remained a significant issue in the IoT domain (Shaikh et al., 2017) as the communication processes are using more power and the IoT-based devices (Maksimović & Omanović-Mikličanin, 2017) are operating with limited energy. Another problem associated with G-IoT is how to use software and the hardware in a way to minimize energy utilization, be developed and collaborate with others, and, at the same time, meet the security/privacy requirements. Two remarkable issues that impact the G-IoT deployment are the engagement of the computing techniques and the incessant developments in communication technologies (Abedin et al., 2015).

G-IoT is still suffering from numerous challenges from numerous perspectives despite many efforts made in the literature for developing IoT-based technologies (Sobreira et al., 2020). There is a need for a remarkable technological innovation to make effective connections among millions of devices with the internet with a confined radio spectrum for several aims such as perceptively organizing physical devices for complex tasks, efficiently integrating big data analysis, and Edge/Fog/Cloud computing for smart operations, realizing more realistic energy consumption by various parts of G-IoT systems, using flexibly and validating the technological innovation reliably in existing systems. To satisfy all the above-noted requirements causes several challenges on the G-IoT evolution. Such challenges need to be well addressed to make sure of a huge release of G-IoT-based technologies. The current study attempts to clearly explain the G-IoT concepts and elaborate on automation and data exchange trends in manufacturing technologies. In addition, this paper highlights the challenges to G-IoT accomplishment. This study is particularly focused upon the challenges that may arise with the requirement for a number of issues to apply the G-IoT technologies in an effective way. Moreover, the present research systematically reviews the latest research efforts and potential areas for future research to address G-IoT's challenges properly. This study has carried out a survey approach using literature review and expert's opinion to provide a comprehensive framework to identify the important challenges to evaluate and implement G-IoT technologies for development with a high level of sustainability. The results obtained by this survey approach are presented in Table 1 and Figure 1.

Table 1. G-IoT technologies challenges towards the achievements of sustainable development

Challenges	References
Routing for low-end devices (L_1)	Conti et al. (2020); Safara et al. (2020)
Green architectures (L_2)	Ullah et al. (2020); Raut and Dhanya (2020)
Reduction of CO_2 footprint of ICT (L_3)	Das and Mao (2020); Bithi et al. (2020)
Smart connected world (L_4)	Horák et al. (2020); Ayoobkhan et al. (2021)
Low range communication protocols (L_5)	Glória et al. (2017); Arya and Gore (2020)
Machine-to-machine (M2M) standardization protocols (L_6)	Thota and Kim (2016); Prasad and Rohokale (2020)
Training of green communications (L_7)	Tabaa et al. (2020); Solanki and Nayyar (2019)
Radio-frequency identification (RFID) technology (L_8)	Noori et al. (2020); Shan et al. (2018)
ZigBee standardization (L_9)	Zemrane et al. (2018); Wang et al. (2019)
Internet protocol version-6 (IPv6) for low-end devices (L_{10})	Hahm et al. (2016); Gomes et al. (2018)
Green infrastructure (L_{11})	Maksimovic (2018); Adila et al. (2018)
Green networking (L_{12})	Rani et al. (2015); Lyu et al. (2018)
Green spectrum management (L_{13})	Albreem et al. (2017); Zhu et al. (2015)
Green communication and connectivity (L_{14})	Popli et al. (2019); Tuysuz and Trestian (2020)
Green service management (L_{15})	Guo et al. (2017); Tuysuz and Trestian (2020)
Interoperability (L_{16})	Ahmad et al. (2019); Ganzha et al. (2018)
Complexity and scalability (L_{17})	Barnaghi and Sheth (2016); Varga et al. (2018)

End of Table 1

Challenges	References
Adaptation to natural energy sources (L_{18})	Tuysuz and Trestian (2020); Gubbi et al. (2013)
Power management in terms of energy efficiency of ICT, data, computing, wireless networks, etc. (L_{19})	Collotta and Pau (2015); Sun et al. (2021)
Information security and privacy protection (L_{20})	Safa et al. (2020); Ning et al. (2020)
Quality of service (QoS) provisioning (L_{21})	Zhang et al. (2016); Badawy et al. (2020)
Governance and legislation (L_{22})	Vong et al. (2014); Vong et al. (2013)
Green policies and standardization (L_{23})	Zhu et al. (2015); Tuysuz and Trestian (2020)

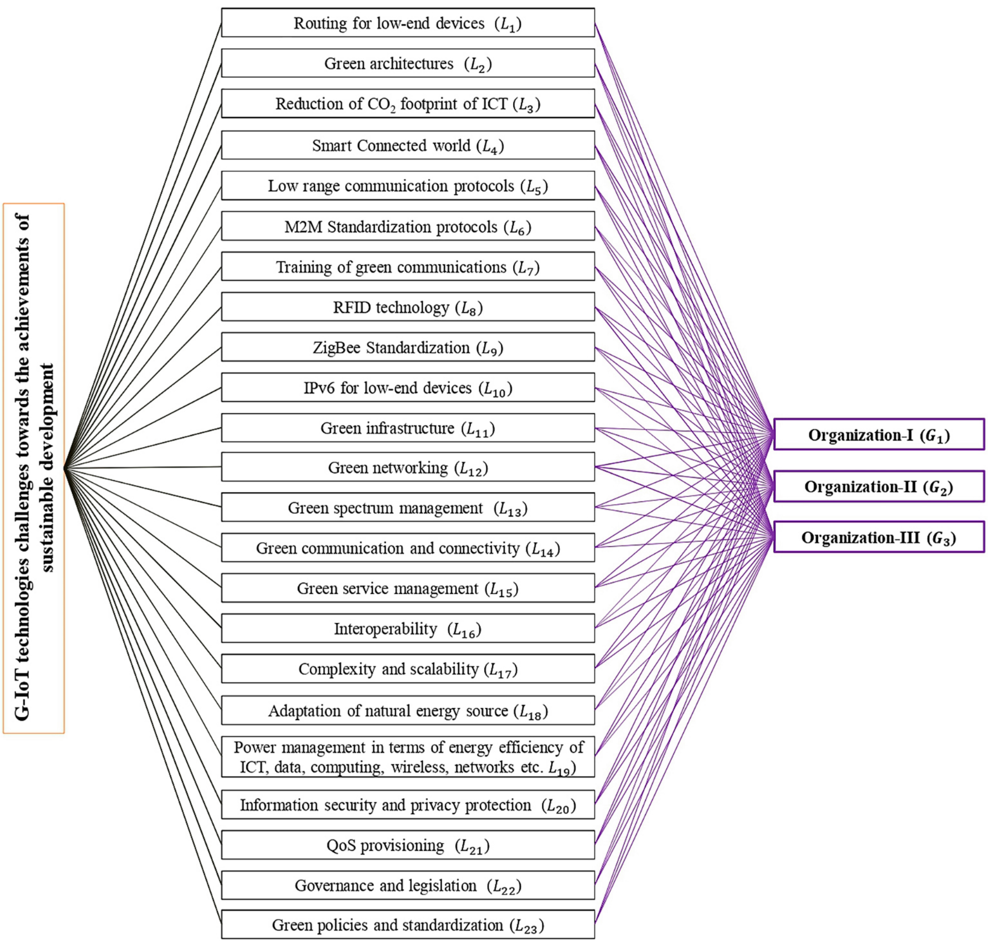

Figure 1. Hierarchical framework of the PF-SWARA-ARAS method to implement of G-IoT technologies

2. Proposed research method

2.1. Preliminaries

This section is presented the basic notions about the PFSs.

Definition 1 (Yager, 2014). A PFS H on fixed set X is given as $H=\left\{\left\langle x_i,\left(b_H(x_i),n_H(x_i)\right)\right\rangle \middle| x_i\in X\right\}$, where $b_H,n_H:X\to[0,1]$ signify the BG and NG of an element $x_i\in X$ to H, respectively, with condition $0\le\left(b_H\left(x_i\right)\right)^2+\left(n_H\left(x_i\right)\right)^2\le 1$. The indeterminacy grade is given by $\pi_H(x_i)=\sqrt{1-b_H^2(x_i)-n_H^2(x_i)}$. Also, Zhang and Xu (2014) described the Pythagorean fuzzy number (PFN), articulated as $\sigma=\left(b_\sigma,n_\sigma\right)$such that $b_\sigma,n_\sigma\in[0,1]$ and $0\le b_\sigma^2+n_\sigma^2\le 1$.

Definition 2 (Zhang & Xu, 2014). Let $\sigma=\left(b_\sigma,n_\sigma\right)\in PFS(X)$ The score and accuracy values of σ are defined as

$$s(\sigma)=\left(b_\sigma\right)^2-\left(n_\sigma\right)^2 \text{ and } a(\sigma)=\left(b_\sigma\right)^2+\left(n_\sigma\right)^2, \tag{1}$$

where $s(\sigma)\in[-1,1]$ and $a(\sigma)\in[0,1]$.

As $s(\sigma)\in[-1,1]$, then normalized score value (Rani et al., 2021) of σ is defined by

Definition 3. Let $\sigma=\left(b_\sigma,n_\sigma\right)\in PFS(X)$. The improved score and uncertainty values of 'σ' are defined as

$$s^*(\sigma)=\frac{1}{2}\left(s(\sigma)+1\right) \text{ and } a^*(\sigma)=1-a(\sigma), \text{ such that } s^*(\sigma),\, a^*(\sigma)\in[0,1]. \tag{2}$$

Definition 4 (Yager, 2013, 2014). Let $\sigma=\left(b_\sigma,n_\sigma\right)$, $\sigma_1=\left(b_{\sigma_1},n_{\sigma_1}\right)$, $\sigma_2=\left(b_{\sigma_2},n_{\sigma_2}\right)\in PFSs(X)$. Then, the basic operations on PFNs are defined by

(i) $\sigma^c=\left(n_\sigma,b_\sigma\right)$,

(ii) $\sigma_1\oplus\sigma_2=\left(\sqrt{b_{\sigma_1}^2+b_{\sigma_2}^2-b_{\sigma_1}^2 b_{\sigma_2}^2},n_{\sigma_1}n_{\sigma_2}\right)$;

(iii) $\sigma_1\otimes\sigma_2=\left(b_{\sigma_1}b_{\sigma_2},\sqrt{n_{\sigma_1}^2+n_{\sigma_2}^2-n_{\sigma_1}^2 n_{\sigma_2}^2}\right)$;

(iv) $\lambda\sigma=\left(\sqrt{1-\left(1-b_\sigma^2\right)^\lambda},\left(n_\sigma\right)^\lambda\right)$, $\lambda>0$;

(v) $\sigma^\lambda=\left(\left(b_\sigma\right)^\lambda,\sqrt{1-\left(1-n_\sigma^2\right)^\lambda}\right)$, $\lambda>0$.

Definition 5 (Zhang & Xu, 2014). Let $\sigma_1=\left(b_{\sigma_1},n_{\sigma_1}\right)$, $\sigma_2=\left(b_{\sigma_2},n_{\sigma_2}\right)\in PFSs(X)$. Then the distance between σ_1 and σ_2 is defined as

$$D\left(\sigma_1,\sigma_2\right)=\frac{1}{2}\left(\left|b_{\sigma_1}^2-b_{\sigma_2}^2\right|+\left|n_{\sigma_1}^2-n_{\sigma_2}^2\right|+\left|\pi_{\sigma_1}^2-\pi_{\sigma_2}^2\right|\right). \tag{3}$$

2.2. Proposed Pythagorean fuzzy SWARA-ARAS approach

In this section, an integrated methodology is presented through integrating SWARA and ARAS on PFSs. SWARA can efficiently estimate the subjective criteria weights (Kersuliene et al., 2010). Its an important benefit in determining the accuracy of the DEs' outlooks regarding the weights allocated by SWARA. In addition, ARAS uses the concet of optimality degree to assess the priority order of each available option considering multiple criteria. As a result, the present research proposes a combined PF-SWARA-ARAS model based on PFSs, criteria weights determined using SWARA, and the assessment of the options preference using ARAS. In the following, the structure is demonstrated as (see Figure 2).

Step 1. Define the MCDM problem

Consider that set of options $G=\{G_1,G_2,...,G_p\}$ over a set of criteria $L=\{L_1,L_2,...,L_q\}$. Let $P=\left(\varepsilon_{ij}^{(k)}\right)$, $\forall i,j$ be decision matrix (DM) given by the l DEs $E=\{e_1,e_2,...,e_l\}$, in which $\varepsilon_{ij}^{(k)}$ means the assessment of an option G_i over the attribute L_j in the form of a PFN.

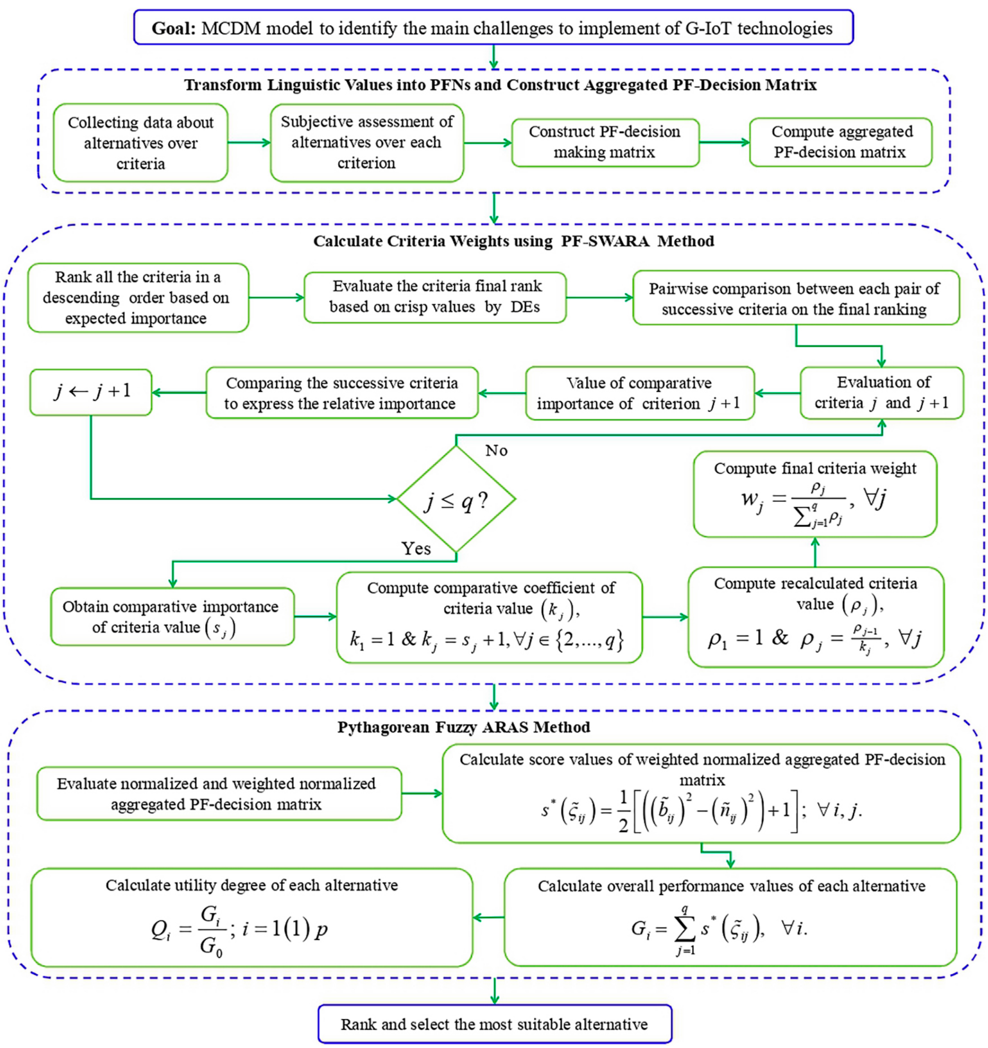

Figure 2. Diagram of the PF-SWARA-ARAS model to implement of G-IoT technologies

Step 2. Assess the DEs' weights

Assume that the DEs' weight is expressed using linguistic values (LVs) and then converted into PFNs. For evaluating k^{th} DE's weight, let (b_k, n_k) be the grade of DEs determined by a DE in the form of a PFN; afterward, the weight is computed as

$$\varpi_k = \frac{\left(b_k^2 + \pi_k^2 \times \left(\frac{b_k^2}{b_k^2 + n_k^2}\right)\right)}{\sum_{k=1}^{\ell}\left(b_k^2 + \pi_k^2 \times \left(\frac{b_k^2}{b_k^2 + n_k^2}\right)\right)}, \; k = 1(1)\ell, \tag{4}$$

where $\varpi_k \geq 0$ and $\sum_{k=1}^{\ell} \varpi_k = 1.$

Step 3. Generate the aggregated Pythagorean fuzzy-decision matrix (APF-DM)

To generate the APF-DM, the PFWA operator is applied as follows:

$$A = \left(\varepsilon_{ij}\right)_{p \times q}, \tag{5}$$

where $\varepsilon_{ij} = PFWA_{\lambda}\left(\varepsilon_{ij}^{(1)}, \varepsilon_{ij}^{(2)}, \ldots, \varepsilon_{ij}^{(\ell)}\right) = \left(\sqrt{1 - \prod_{k=1}^{\ell}\left(1 - b_k^2\right)^{\varpi_k}}, \; \prod_{k=1}^{\ell}\left(n_k\right)^{\varpi_k}\right).$

Step 4. Assess the criteria weights by the SWARA model.

The procedure for computing the criteria weights is given by

Step 4.1. Compute the crisp degrees. The score degree $s^*\left(\varepsilon_{kj}\right)$ of PFN is estimated by Eq. (2).

Step 4.2. Prioritize the criteria. The criteria are arranged using the DE's prioritization from the most significant to the least significant attribute.

Step 4.3. Compute the relative significance of the average degree. The relative significance is estimated from the criteria that are graded in the second place, and the following relative significance is computed by comparing attribute L_j and attribute L_{j-1}.

Step 4.4. Obtain the relative coefficient. The coefficient κ_j is calculated as follows:

$$\kappa_j = \begin{cases} 1, & j = 1 \\ s_j + 1, & j > 1, \end{cases} \tag{6}$$

where s_j denotes the relative significance.

Step 4.5. Compute the weights. The recalculated weight ρ_j is given by

$$\rho_j = \begin{cases} 1, & j = 1 \\ \frac{\rho_{j-1}}{\kappa_j}, & j > 1. \end{cases} \tag{7}$$

Step 4.6. Estimate the normalized weight. The criteria weights are normalized as

$$w_j = \frac{\rho_j}{\sum_{j=1}^{q} \rho_j}. \tag{8}$$

Step 5. Appraise the optimal performance grade

$$G_0 = \begin{cases} \max \varepsilon_{ij}, & j \in L_b \\ \min \varepsilon_{ij}, & j \in L_n, \end{cases} \tag{9}$$

where L_b and L_n are benefit and cost attributes, respectively.

Step 6. Make a normalized APF-DM (NAPF-DM)

The NAPF-DM $U = \left(\varsigma_{ij}\right)_{p \times q}$ is estimated as

$$\varsigma_{ij} = \begin{cases} \varepsilon_{ij} = \left(b_{ij}, n_{ij}\right), & j \in L_b \\ \left(\varepsilon_{ij}\right)^c = \left(n_{ij}, b_{ij}\right), & j \in L_n \end{cases}, \ \forall i, j. \tag{10}$$

Step 7. Compute the weighted NAPF-DM (WNAPF-DM)

The WNAPF-DM $U_w = \left(\tilde{\varsigma}_{ij}\right)_{p \times q}$ is created as

$$\tilde{\varsigma}_{ij} = \left\langle \tilde{b}_{ij}, \tilde{n}_{ij} \right\rangle = \mathop{\oplus}_{j=1}^{q} w_j \varsigma_{ij} = \left\langle \sqrt{1 - \prod_{j=1}^{q} \left(1 - b_{ij}\right)^{w_j}}, \prod_{j=1}^{q} \left(n_{ij}\right)^{w_j} \right\rangle, \tag{11}$$

Step 8. Appraise the score degrees

From Eq. (3), the score degrees of WNAPF-DM $U_w = \left(\tilde{\varsigma}_{ij}\right)_{p \times q}$ are estimated by

$$s^*\left(\tilde{\varsigma}_{ij}\right) = \frac{1}{2}\left[\left(\left(\tilde{b}_{ij}\right)^2 - \left(\tilde{n}_{ij}\right)^2\right) + 1\right], \ \forall i, j. \tag{12}$$

Step 9. Obtain the overall performance values and utility degree

The overall performance degrees are assessed as

$$G_i = \sum_{j=1}^{q} s^*\left(\tilde{\varsigma}_{ij}\right), \ \forall i. \tag{13}$$

The optimum option is the one with the highest degree of G_i, whereas the worst option is the one with the lowest degree of G_i.

During the MCDM process, the users must calculate the optimal option and, at the same time, explore the virtual impact of the achieved options, considering the most favored alternative. The utility degree Q_i of alternative G_i: i = 1(1)p is given by

$$Q_i = \frac{G_i}{G_0}; \ i = 1(1)p, \ Q_i \in [0,1]. \tag{14}$$

Step 10. Select the most desired option

The determined options are put in a ranking order based on the ascending order of Q_i. This means that the option that has the highest degree of G^* is more appropriate for the process and so on. For that reason, the optimum option can be calculated using the equation below:

$$G^* = \left\{G_i \mid \max_i Q_i; \ i = 1(1)p\right\}. \tag{15}$$

3. Results

3.1. Case study

For the purpose of the present study, four key manufacturing firms were investigated thoroughly to develop and refine the model in the development phase, and the model constructed was finally applied to the firms' evaluation. The four firms evaluated were 1) a machine and plant engineering manufacturer, 2) an automotive manufacturer, 3) an electrical engineering manufacturer, and 4) a medical engineering manufacturer. The required data were gathered by means of in-depth interviews, discussions, and meetings held in workshops with the firms. To sketch a picture of the effect of G-IoT on the manufacturing context with a higher generalizability, this study attempted to select samples from manufacturers from various branches and of various sizes. The branches considered were machinery and plant engineering, electrical engineering, automotive, medical engineering, and ICT, which represent the key industries in China regarding the way they contribute to the Gross Domestic Product (GDP). The participating firms are all located in China because G-IoT (which is a synonym for Industry 4.0 in the Chinese context) plays a crucial role in China's high-tech strategy 2020. It was necessary to choose from among the firms influenced by G-IoT from organizational perspectives. It can result in the achievement of information of high reliability and competency. The selections of the manufacturers were made based on their innovativeness and leadership in different emerging and mature market segments. The variety of the cases selected for this research is supposed to enhance the variety of the data in a way to contribute to theory building. The experts were required to have a middle or top management position and to be completely involved in implementing G-IoT. In general, a total of 10 interviews were held from June 2020 to September 2020. Specifically, three

Table 2. LVs for evaluating the performance of attribute

LVs	PFNs
Extremely significant (ES)	(0.90, 0.15, 0.409)
Very very significant (VVS)	(0.75, 0.40, 0.527)
Very significant (VS)	(0.70, 0.55, 0.456)
Significant (S)	(0.60, 0.70, 0.387)
Less significant (LS)	(0.40, 0.80, 0.447)
Very less significant (VLS)	(0.30, 0.90, 0.316)

Table 3. LVs for the options and barriers

LVs	PFNs
Absolutely high (AH)	(0.95, 0.20, 0.387)
Very very high (VVH)	(0.85, 0.30, 0.433)
Very high (VH)	(0.80, 0.35, 0.487)
High (H)	(0.70, 0.45, 0.554)
Above average (AA)	(0.60, 0.55, 0.581)
Average (A)	(0.50, 0.60, 0.624)
Below average (BA)	(0.40, 0.70, 0.592)
Low (L)	(0.30, 0.75, 0.589)
Very low (VL)	(0.20, 0.85, 0.487)
Absolutely low (AL)	(0.10, 0.95, 0.296)

Table 4. Weight of DEs for evaluation the options

DEs	LVs	PFNs	Weights
e_1	ES	(0.90, 0.15, 0.409)	0.4104
e_2	VVS	(0.75, 0.40, 0.527)	0.3286
e_3	VS	(0.70, 0.55, 0.456)	0.2610

interviews were carried out with electrical engineering manufacturers, three interviews with machine and plant engineering manufacturers, two with the medical engineering manufacturers, and two with the automotive manufacturers. In the present research, the proposed approach was used to evaluate and analyze the challenges encountered by manufacturing companies when they are implementing G-IoT technologies for development with a high level of sustainability. Tables 2 and 3, adopted from Rani et al. (2020), and Liu et al. (2021), use LVs to present the importance of the DEs and criteria; LVs are translated in these tables into PFNs. Then, Table 4 gives the DEs' weight on the basis of Table 2 and Eq. (4). The DEs' significance is then presented in Table 5 as (e_1, e_2, e_3) in order to assess the options considering each criterion.

Decisions given by three experts have been accumulated by Eq. (5) for alternatives over diverse challenges to implement the G-IoT technologies into an APF-DM $A = \left(\varepsilon_{ij}\right)_{p\times q}$, and are presented in Table 6.

Table 5. LVs of alternative under different challenges to implement of G-IoT by DEs

	G_1	G_2	G_3
L_1	(AA, A, H)	(A, BA, VL)	(H, AA, A)
L_2	(A, VH, H)	(BA, AA, H)	(H, A, AA)
L_3	(H, VH, H)	(VH, H, VH)	(BA, A, H)
L_4	(BA, A, H)	(VH, A, H)	(BA, BA, AA)
L_5	(BA, AA, H)	(BA, H, H)	(AA, BA, A)
L_6	(VL, AA, L)	(A, VL, L)	(VH, H, A)
L_7	(BA, MH, L)	(L, VL, L)	(A, AA, A)
L_8	(H, VH, VH)	(A, H, VH)	(BA, A, AA)
L_9	(H, A, H)	(A, VH, H)	(A, BA, H)
L_{10}	(L, L, A)	(L, VL, VL)	(L, A, BA)
L_{11}	(BA, L, L)	(AA, L, L)	(AA, H, A)
L_{12}	(BA, L, BA)	(BA, A, ML)	(H, VH, A)
L_{13}	(BA, VL, VL)	(L, BA, L)	(BA, A, BA)
L_{14}	(BA, A, H)	(BA, AA, H)	(AA, VVH, AA)
L_{15}	(VH, AA, A)	(BA, VH, H)	(A, BA, VH)
L_{16}	(BA, L, VL)	(A, L, VL)	(AA, A, VH)
L_{17}	(BA, BA, A)	(L, VL, ML)	(AA, BA, A)
L_{18}	(AA, VH, H)	(A, VH, H)	(A, VL, BA)
L_{19}	(BA, A, H)	(AA, VVH, H)	(BA, AA, A)
L_{20}	(AA, H, H)	(A, AA, A)	(BA, VL, A)
L_{21}	(AA, L, H)	(A, A, A)	(BA, L, A)
L_{22}	(AA, AA, H)	(A, BA, A)	(BA, BA, A)
L_{23}	(AA, A, H)	(AA, BA, A)	(BA, L, AA)

Table 6. APF-DM for alternatives over different challenges to implementing of G-IoT technologies

	G_1	G_2	G_3
L_1	(0.604, 0.537, 0.589)	(0.412, 0.691, 0.594)	(0.626, 0.518, 0.582)
L_2	(0.683, 0.466, 0.562)	(0.571, 0.576, 0.585)	(0.621, 0.521, 0.585)
L_3	(0.738, 0.414, 0.532)	(0.772, 0.380, 0.509)	(0.538, 0.593, 0.599)
L_4	(0.538, 0.575, 0.616)	(0.706, 0.446, 0.550)	(0.466, 0.657, 0.592)
L_5	(0.571, 0.559, 0.602)	(0.612, 0.539, 0.579)	(0.520, 0.609, 0.599)
L_6	(0.414, 0.713, 0.566)	(0.380, 0.713, 0.589)	(0.715, 0.438, 0.545)
L_7	(0.464, 0.658, 0.592)	(0.272, 0.781, 0.562)	(0.537, 0.583, 0.610)
L_8	(0.765, 0.388, 0.515)	(0.674, 0.474, 0.566)	(0.496, 0.625, 0.603)
L_9	(0.649, 0.495, 0.578)	(0.683, 0.466, 0.562)	(0.544, 0.586, 0.601)
L_{10}	(0.367, 0.708, 0.604)	(0.247, 0.807, 0.536)	(0.405, 0.685, 0.606)
L_{11}	(0.346, 0.729, 0.591)	(0.461, 0.660, 0.593)	(0.617, 0.527, 0.585)
L_{12}	(0.371, 0.716, 0.591)	(0.437, 0.665, 0.605)	(0.705, 0.447, 0.551)
L_{13}	(0.302, 0.785, 0.541)	(0.337, 0.733, 0.591)	(0.437, 0.665, 0.605)
L_{14}	(0.538, 0.593, 0.599)	(0.571, 0.576, 0.585)	(0.717, 0.451, 0.532)
L_{15}	(0.724, 0.434, 0.537)	(0.665, 0.497, 0.558)	(0.598, 0.548, 0.585)
L_{16}	(0.327, 0.753, 0.571)	(0.384, 0.707, 0.594)	(0.648, 0.503, 0.572)
L_{17}	(0.430, 0.672, 0.603)	(0.305, 0.768, 0.564)	(0.520, 0.609, 0.599)
L_{18}	(0.708, 0.450, 0.545)	(0.683, 0.466, 0.562)	(0.403, 0.700, 0.589)
L_{19}	(0.538, 0.593, 0.599)	(0.736, 0.428, 0.525)	(0.504, 0.621, 0.600)
L_{20}	(0.663, 0.489, 0.567)	(0.537, 0.583, 0.610)	(0.385, 0.717, 0.582)
L_{21}	(0.568, 0.578, 0.586)	(0.500, 0.600, 0.624)	(0.403, 0.688, 0.603)
L_{22}	(0.630, 0.522, 0.575)	(0.471, 0.631, 0.617)	(0.430, 0.672, 0.603)
L_{23}	(0.604, 0.537, 0.589)	(0.520, 0.609, 0.599)	(0.444, 0.672, 0.593)

When computing each barrier's weight with the help of SWARA, the DEs play significant roles in assessing and compute the weights presented in Table 7. In this study, each expert selected the significance of each challenge; then, using Eqs (6)–(8), the experts ranked all the criteria. Each expert is expected to employ their own implicit experiences, information, and knowledge in this process. In SWARA, the barrier of the highest importance is ranked first, while the least important one is ranked the last. Based on the average value of the ranks, the overall ranks of the DEs were determined. Table 8 displays the weight values of all challenges as the w_j column. Hence, the final weight of the challenges to the utilization of G-IoT technologies for development with a higher level of sustainability is presented as

w_j = (0.0419, 0.0445, 0.0373, 0.0424, 0.0358, 0.0508, 0.0446, 0.0434, 0.0406, 0.0467, 0.0403, 0.0428, 0.0420, 0.0454, 0.0447, 0.0442, 0.0409, 0.0479, 0.0431, 0.0469, 0.0448, 0.0458, 0.0432).

Here, Figure 3 shows the importance, degree, or weights of various challenges to implement G-IoT technologies towards sustainable development achievements with respect to the goal. M2M standardization protocols (L_6) with a weight value of 0.0508 have the most important challenges to implement G-IoT technologies. Adaptation to natural energy sources

Table 7. Weights of challenges to implementing G-IoT technologies in LVs

Challenges	e_1	e_2	e_3	Aggregated PFNs	Crisp values $s^*(\varepsilon_{kj})$
L_1	BA	AA	BA	(0.481, 0.647, 0.592)	0.407
L_2	A	A	AA	(0.530, 0.587, 0.613)	0.468
L_3	L	BA	L	(0.337, 0.733, 0.591)	0.288
L_4	A	A	BA	(0.477, 0.625, 0.618)	0.419
L_5	VL	L	BA	(0.298, 0.775, 0.556)	0.244
L_6	AA	H	H	(0.663, 0.489, 0.567)	0.601
L_7	BA	A	H	(0.538, 0.593, 0.599)	0.469
L_8	AA	A	L	(0.511, 0.614, 0.602)	0.442
L_9	BA	A	BA	(0.437, 0.665, 0.605)	0.374
L_{10}	H	A	BA	(0.584, 0.555, 0.593)	0.516
L_{11}	L	BA	AA	(0.438, 0.676, 0.593)	0.367
L_{12}	BA	A	AA	(0.496, 0.625, 0.603)	0.428
L_{13}	AA	BA	L	(0.483, 0.646, 0.592)	0.408
L_{14}	H	BA	BA	(0.562, 0.584, 0.586)	0.487
L_{15}	AA	AA	L	(0.546, 0.596, 0.588)	0.471
L_{16}	BA	H	BA	(0.536, 0.605, 0.589)	0.460
L_{17}	L	AA	BA	(0.454, 0.665, 0.593)	0.382
L_{18}	BA	AA	AA	(0.612, 0.539, 0.579)	0.542
L_{19}	A	BA	AA	(0.503, 0.617, 0.605)	0.436
L_{20}	BA	A	VH	(0.593, 0.555, 0.583)	0.521
L_{21}	AA	BA	AA	(0.548, 0.595, 0.588)	0.473
L_{22}	BA	AA	H	(0.571, 0.576, 0.585)	0.497
L_{23}	L	H	BA	(0.513, 0.623, 0.591)	0.438

(L_{18}) with a weight value of 0.0479 is the second most important challenge to implement G-IoT technologies. Information security and privacy protection (L_{20}) has third with a weight of 0.0469, IPv6 for low-end devices (L_{10}) has fourth with a weight of 0.0467, governance and legislation (L_{22}) with a weight of 0.0458 as the fifth most significant challenge to implement of G-IoT technologies and others are considered crucial challenges to implement of G-IoT technologies towards the SDAs.

Afterward, the optimum performance rating of options to use G-IoT technologies for a development with a high level of sustainability is determined using Eq. (9). The obtained optimal performance ratings of rank the organizations and analysis the main challenges to implement of G-IoT technologies are:

G_0 ={(0.626, 0.518, 0.582), (0.683, 0.466, 0.562), (0.772, 0.380, 0.509), (0.706, 0.446, 0.550), (0.612, 0.539, 0.579), (0.715, 0.438, 0.545), (0.537, 0.583, 0.610), (0.765, 0.388, 0.515), (0.683, 0.466, 0.562), (0.405, 0.685, 0.606), (0.617, 0.527, 0.585), (0.705, 0.447, 0.551), (0.437, 0.665, 0.605), (0.717, 0.451, 0.532), (0.724, 0.434, 0.537), (0.648, 0.503, 0.572), (0.520, 0.609, 0.599), (0.708, 0.450, 0.545), (0.736, 0.428, 0.525), (0.663, 0.489, 0.567), (0.568, 0.578, 0.586), (0.630, 0.522, 0.575), (0.604, 0.537, 0.589)}.

As all attributes are of benefit-types thus, there is no need to normalize APF-DM. By Eq. (11), the WNAPF-DM is discussed in Table 9.

Table 8. Significance degree of challenges to implementing of G-IoT technologies using SWARA method

Challenges	Crisp values	Relative significance of criteria value (s_j)	Coefficient (k_j)	Recalculated weight (p_j)	Final weight (w_j)
L_6	0.601	–	1.000	1.000	0.0508
L_{18}	0.542	0.059	1.059	0.9443	0.0479
L_{20}	0.521	0.021	1.021	0.9249	0.0469
L_{10}	0.516	0.005	1.005	0.9203	0.0467
L_{22}	0.497	0.019	1.019	0.9031	0.0458
L_{14}	0.487	0.010	1.010	0.8942	0.0454
L_{21}	0.473	0.014	1.014	0.8818	0.0448
L_{15}	0.471	0.002	1.002	0.8800	0.0447
L_7	0.469	0.002	1.002	0.8782	0.0446
L_2	0.468	0.001	1.001	0.8773	0.0445
L_{16}	0.460	0.008	1.008	0.8703	0.0442
L_8	0.442	0.018	1.018	0.8549	0.0434
L_{23}	0.438	0.004	1.004	0.8515	0.0432
L_{19}	0.436	0.002	1.002	0.8498	0.0431
L_{12}	0.428	0.008	1.008	0.8431	0.0428
L_4	0.419	0.009	1.009	0.8356	0.0424
L_{13}	0.408	0.011	1.011	0.8265	0.0420
L_1	0.407	0.001	1.001	0.8257	0.0419
L_{17}	0.382	0.025	1.025	0.8056	0.0409
L_9	0.374	0.008	1.008	0.7992	0.0406
L_{11}	0.367	0.007	1.007	0.7936	0.0403
L_3	0.288	0.079	1.079	0.7355	0.0373
L_5	0.244	0.044	1.044	0.7045	0.0358

Table 9. WNAPF-DM for options over different challenges to implementing of G-IoT technologies

	G_0	G_1	G_2	G_3
L_1	(0.144, 0.973, 0.182)	(0.137, 0.974, 0.179)	(0.088, 0.985, 0.151)	(0.144, 0.973, 0.182)
L_2	(0.166, 0.967, 0.195)	(0.166, 0.967, 0.195)	(0.132, 0.976, 0.175)	(0.146, 0.971, 0.187)
L_3	(0.182, 0.965, 0.191)	(0.170, 0.968, 0.186)	(0.182, 0.965, 0.191)	(0.113, 0.981, 0.160)
L_4	(0.170, 0.966, 0.193)	(0.120, 0.977, 0.177)	(0.170, 0.966, 0.193)	(0.102, 0.982, 0.157)
L_5	(0.129, 0.978, 0.163)	(0.118, 0.979, 0.164)	(0.129, 0.978, 0.163)	(0.106, 0.982, 0.154)
L_6	(0.189, 0.959, 0.212)	(0.097, 0.983, 0.156)	(0.089, 0.983, 0.161)	(0.189, 0.959, 0.212)
L_7	(0.123, 0.976, 0.179)	(0.104, 0.982, 0.161)	(0.058, 0.989, 0.135)	(0.123, 0.976, 0.179)
L_8	(0.194, 0.960, 0.204)	(0.193, 0.960, 0.204)	(0.161, 0.968, 0.192)	(0.110, 0.980, 0.167)
L_9	(0.159, 0.969, 0.187)	(0.148, 0.972, 0.183)	(0.159, 0.969, 0.187)	(0.119, 0.979, 0.168)
L_{10}	(0.091, 0.982, 0.162)	(0.082, 0.984, 0.158)	(0.054, 0.990, 0.130)	(0.091, 0.982, 0.163)
L_{11}	(0.138, 0.975, 0.177)	(0.071, 0.987, 0.142)	(0.098, 0.983, 0.153)	(0.138, 0.974, 0.177)
L_{12}	(0.170, 0.966, 0.194)	(0.079, 0.986, 0.148)	(0.095, 0.983, 0.159)	(0.170, 0.966, 0.194)
L_{13}	(0.094, 0.983, 0.158)	(0.063, 0.990, 0.127)	(0.071, 0.987, 0.144)	(0.094, 0.983, 0.157)
L_{14}	(0.180, 0.964, 0.194)	(0.124, 0.977, 0.176)	(0.133, 0.975, 0.176)	(0.179, 0.964, 0.194)
L_{15}	(0.181, 0.963, 0.198)	(0.181, 0.963, 0.198)	(0.160, 0.969, 0.187)	(0.140, 0.973, 0.181)
L_{16}	(0.154, 0.970, 0.187)	(0.071, 0.988, 0.141)	(0.084, 0.985, 0.152)	(0.154, 0.970, 0.188)
L_{17}	(0.113, 0.980, 0.164)	(0.091, 0.984, 0.154)	(0.063, 0.989, 0.132)	(0.113, 0.980, 0.164)
L_{18}	(0.181, 0.962, 0.202)	(0.181, 0.962, 0.202)	(0.172, 0.964, 0.202)	(0.092, 0.983, 0.158)
L_{19}	(0.182, 0.964, 0.194)	(0.121, 0.978, 0.172)	(0.182, 0.964, 0.194)	(0.112, 0.980, 0.166)
L_{20}	(0.164, 0.967, 0.195)	(0.164, 0.967, 0.195)	(0.126, 0.975, 0.183)	(0.086, 0.984, 0.153)
L_{21}	(0.132, 0.976, 0.175)	(0.132, 0.976, 0.175)	(0.113, 0.977, 0.179)	(0.089, 0.983, 0.158)
L_{22}	(0.151, 0.971, 0.187)	(0.151, 0.971, 0.187)	(0.107, 0.979, 0.173)	(0.096, 0.982, 0.163)
L_{23}	(0.139, 0.973, 0.181)	(0.139, 0.974, 0.181)	(0.116, 0.979, 0.169)	(0.097, 0.983, 0.156)

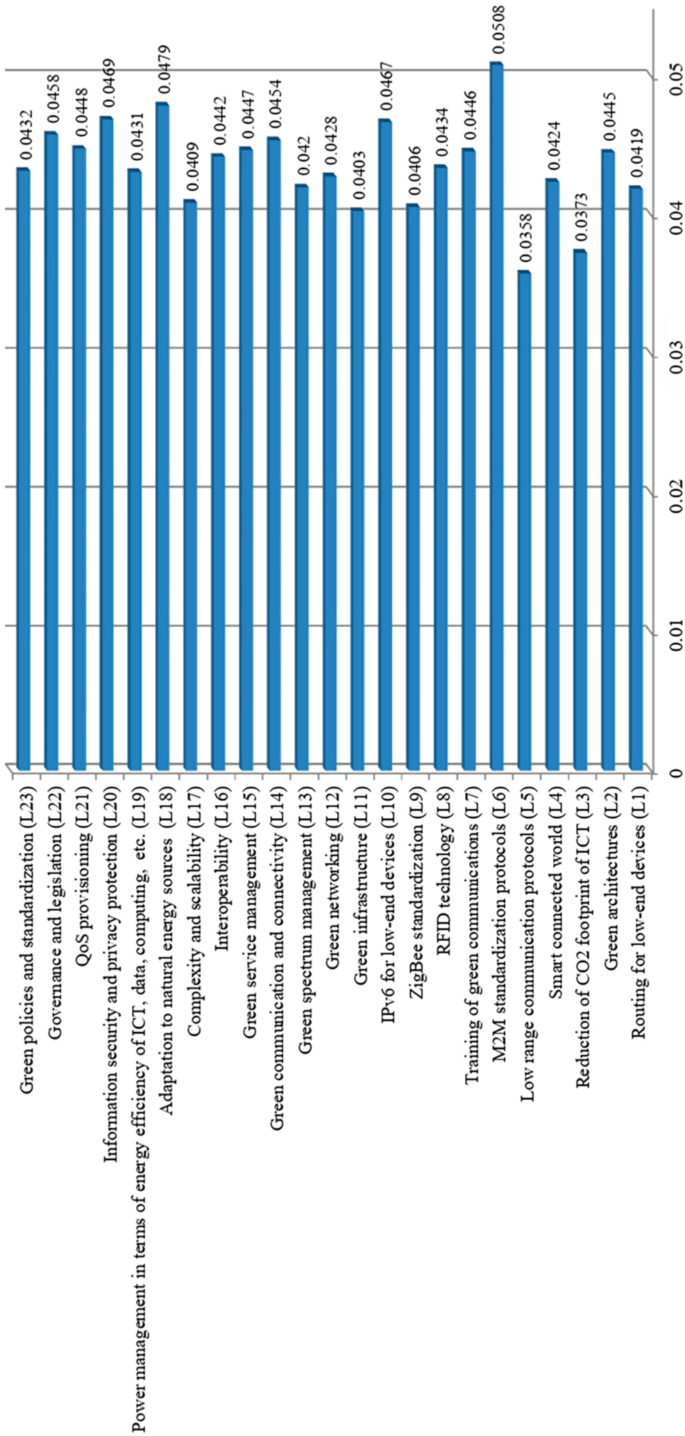

Figure 3. Significance values / weight of challenges to implement of G-IoT technologies

Table 10. Overall performance degree of organization of weighted evaluation matrix

	G_0	G_1	G_2	G_3
L_1	0.037	0.035	0.019	0.037
L_2	0.047	0.047	0.033	0.039
L_3	0.051	0.046	0.051	0.025
L_4	0.048	0.030	0.047	0.023
L_5	0.030	0.027	0.030	0.023
L_6	0.058	0.022	0.021	0.058
L_7	0.031	0.024	0.013	0.031
L_8	0.058	0.058	0.044	0.026
L_9	0.043	0.039	0.043	0.028
L_{10}	0.022	0.019	0.011	0.022
L_{11}	0.035	0.015	0.021	0.035
L_{12}	0.048	0.017	0.022	0.048
L_{13}	0.021	0.012	0.015	0.021
L_{14}	0.051	0.031	0.033	0.051
L_{15}	0.052	0.052	0.043	0.036
L_{16}	0.041	0.015	0.019	0.041
L_{17}	0.026	0.020	0.013	0.026
L_{18}	0.053	0.053	0.050	0.021
L_{19}	0.052	0.029	0.052	0.026
L_{20}	0.046	0.046	0.033	0.019
L_{21}	0.033	0.033	0.029	0.020
L_{22}	0.040	0.040	0.026	0.023
L_{23}	0.036	0.036	0.028	0.022
Overall performance rating	0.959	0.7466	0.6957	0.702
Utility degree	–	0.7789	0.7258	0.7321
Ranking		1	3	2

Next, using Eqs (12)–(13), we compute the score value and overall performance degrees of the weighted evaluation matrix of organizations to implement G-IoT technologies and are presented in Table 10. By Eq. (14), the utility degree $\mathbb{Q}_i$ is estimated by $\mathbb{Q}_1 = 0.7789$, $\mathbb{Q}_2 = 0.7258$, $\mathbb{Q}_3 = 0.7321$. Based on the utility $\mathbb{Q}_i$, the prioritization of the organizations to implement of G-IoT technologies is $G_1 \succ G_3 \succ G_2$, and hence, the organization-I (G_1) is the best one with respect to the different challenges to implementing of G-IoT technologies towards the SDAs.

3.2. Sensitivity analysis

The current study also performed a sensitivity analysis to examine the performance of the proposed approach. Table 11 presents eight criteria weight sets, where, for each set, one of the criteria has the highest weight. This process was performed to create a sufficient scope of attribute weights to examine the sensitivity of the developed model to the attribute weights variation.

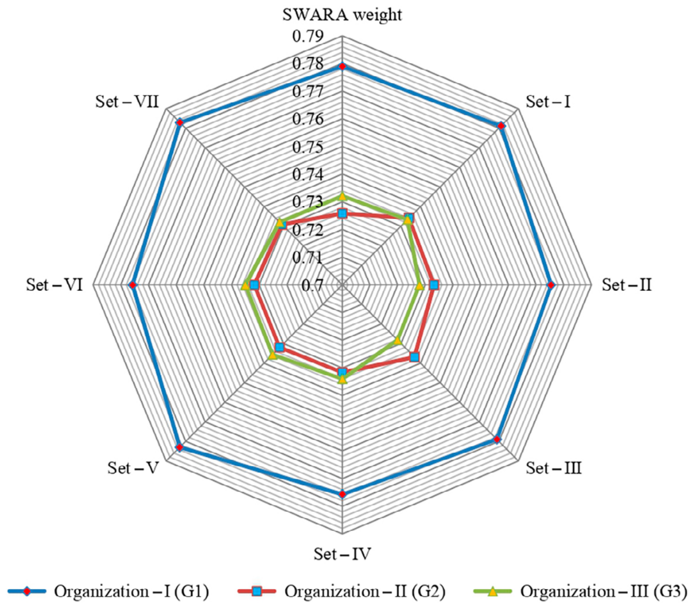

Figure 4. Variation in the utility degree of organizations with different weight sets

The results of sensitivity investigation in Figure 4 indicate that the utility degree $\mathbb{Q}_i$, can be altered over different attribute weight sets and the rank of the organization to the use of G-IoT for the development of high sustainability level. For instance, in cases where the DEs deliver the weight set-I, II, and III, the ranking of the organization to implement of G-IoT technologies towards the SDAs is $G_1 \succ G_2 \succ G_3$, whereas when the evaluation weight set-IV, V, VI, VII, and SWARA weight method is taken, then organization to implement of G-IoT technologies ranking becomes $G_1 \succ G_3 \succ G_2$. From Table 11 and Figure 4, it was observed that option G_1 gained the first rank in the implementation of G-IoT technologies.

Accordingly, it can be said that the decisions of the firm about the use of G-IoT technologies for gaining a development with a high level of sustainability depend upon and the sensitivity to these criteria weight sets. Consequently, the approach proposed in this paper showed an acceptable level of stability with a variety of weight sets. This analysis indicates that the PF-SWARA-ARAS method developed in this study does not depend on any bias, and the obtained results have high stability in their nature.

Table 11. Utility degree of organizations with different weight sets

Option	SWARA weight method	Set – I	Set – II	Set – III	Set – IV	Set – V	Set – VI	Set – VII
G_1	0.7789	0.7811	0.7754	0.779	0.7757	0.783	0.7757	0.7829
G_2	0.7258	0.7341	0.7331	0.7369	0.7317	0.732	0.7318	0.7308
G_3	0.7321	0.7333	0.7279	0.7282	0.734	0.7356	0.735	0.732

3.3. Comparison with extant methods

To certify the PF-SWARA-ARAS framework, we make a comparison with the PF-weighted aggregated sum product assessment (WASPAS) model (Rani et al., 2020), PF-TOPSIS (Ak & Gul, 2019), PF-SWARA-complex proportional assessment (COPRAS) (Alipour et al., 2021), PF-WSM, and PF-WPM. The steps of the PF-WASPAS model as

Steps 1–4. Similar to the preceding model.

Step 5. Compute the weighted sum model (WSM) $\mathbb{C}_i^{(1)}$ measure as follows:

$$\mathbb{C}_i^{(1)} = \sum_{j=1}^{q} w_j \varsigma_{ij}. \tag{16}$$

Step 6. Appraise the weighted product model (WPM) $\mathbb{C}_i^{(2)}$ measure as follows:

$$\mathbb{C}_i^{(2)} = \prod_{j=1}^{q} w_j \varsigma_{ij}. \tag{17}$$

Step 7. Determine the WASPAS measure for each option as

$$\mathbb{C}_i = \lambda\, \mathbb{C}_i^{(1)} + (1-\lambda)\, \mathbb{C}_i^{(2)}, \tag{18}$$

where λ is the combining coefficient of decision accuracy.

Step 8. Priority order of the choices based on descending values of $\mathbb{C}_i$.

Step 9. End.

From Table 6, Eqs (16)–(18), the WASPAS measure $(\mathbb{C}_i)$ for each organization option is computed and given in Table 12 (for λ = 0.5).

Table 12. The outcome of PF- SWARA-WASPAS model

Option	WSM		WPM		$\mathbb{S}^*(\mathbb{C}_i)$	Ranking
	$\mathbb{C}_i^{(1)}$	$\mathbb{S}^*\left(\mathbb{C}_i^{(1)}\right)$	$\mathbb{C}_i^{(2)}$	$\mathbb{S}^*\left(\mathbb{C}_i^{(2)}\right)$		
G_1	(0.611, 0.531, 0.587)	0.545	(0.564, 0.571, 0.596)	0.496	0.5206	1
G_2	(0.597, 0.540, 0.592)	0.532	(0.537, 0.591, 0.603)	0.469	0.5009	2
G_3	(0.576, 0.562, 0.594)	0.508	(0.546, 0.585, 0.600)	0.478	0.4928	3

Thus, the final ranking of the organizations in the implementation of G-IoT technologies for the development of a high level of sustainability is $G_1 \succ G_2 \succ G_3$. As a result; it can be said that the most desired alternative is G_1.

Afterward, the procedure of the PF-SWARA-COPRAS (Alipour et al., 2021) model is presented as

Steps 1–4. Similar to the above-mentioned model.

Step 5. Aggregate the benefit and cost criteria in the APF-DM by Eq. (4). Since all criteria are benefit-type, we compute the following index for each alternative to maximize the preference

$\beta_i = \prod_{j=1}^{q} w_j \varsigma_{ij},\ i = 1(1)p.$ Also, the index degree is similar to the relative degree of each alternative. Hence, we obtain $\lambda_1 = 0.496,\ \lambda_2 = 0.469,$ and $\lambda_3 = 0.478.$

Step 6. Conpute the relative indices of the three organizations using the priority λ_i and get the priority order of given organizations as $\lambda_1 \succ \lambda_3 \succ \lambda_2.$ The ranking reflects that the organization G_1 is the optimal one among the others in the implementation of G-IoT technologies towards the SDAs.

Step 7. Compute the "utility degree" $\hbar_i = \frac{\lambda_i}{\lambda_{\max}} \times 100\%,$ which reveals the utility degree between each organization and the best organization to the implementation of G-IoT technologies towards the SDAs. Then, we obtain $\hbar_1 = 100.00\%,\ \hbar_2 = 94.56\%,$ and $\hbar_5 = 96.37\%.$

Also, using PF-TOPSIS (Ak & Gul, 2019), the final ranking of the organizations in the implementation of G-IoT technologies for the development of a high level of sustainability is $G_1 \succ G_3 \succ G_2$. As a result, it can be said that the most desired alternative is G_1. Consequently, the present study applies various currently-used approaches to the same instance to compare with the outcomes obtained by the developed method (see Figure 5). When compared to currently-implemented model, PF-SWARA-ARAS has the given advantages as

a) PF-SWARA-ARAS works on the basis of a broader standard of ARAS with information measures to select the organizations to implement G-IoT technologies towards the achievements of sustainable development problems in comparison to PF-WASPAS (Utility degree), PF-SWARA-COPRAS (Compromise programming), PF-TOPSIS (Compromise programming), PF-WSM and PF-WPM methods because PF-SWAR-ARAS method considers improved score values (deviations) from optimal alternative while the other methods only consider a single criterion of the minimum distance from PF-IS (ideal solution) and PF-AIS (anti-ideal solution).

b) To concentrate on uncertainty in MCDM problems, all the inputs, specifically the assessments of alternatives on attributes by several decision experts, DEs weights by the experts, and criterion weights by DEs, are taken uncertain classification by the PFNs.

c) For the PF-TOPSIS procedure, an important task is the estimation of the distance between each option on obtained criteria and that of the ideal solutions, which is time-consuming and declines the precision of the results. In PF-SWARA-COPRAS, the aggregated indices are evaluated by the PFWG operator while, in the developed model, the ratio between each alternative and the PF-IS can be described in the form of "utility degree." Also, the assessment procedure of PF-SWARA-ARAS methodology is simple and straightforward, and hence the precision and determination of the results are higher.

d) The developed method only utilizes the PF-IS, whereas PF-TOPSIS needs to assess both PF-IS and PF-AIS, and the PF-WASPAS model uses the PFWAO and PFWGO. To conclude, the decision-making problems with higher numbers criteria or options, the PF-SWARA-ARAS is proficient of to some extent, increasing the operational effectiveness with higher operability.

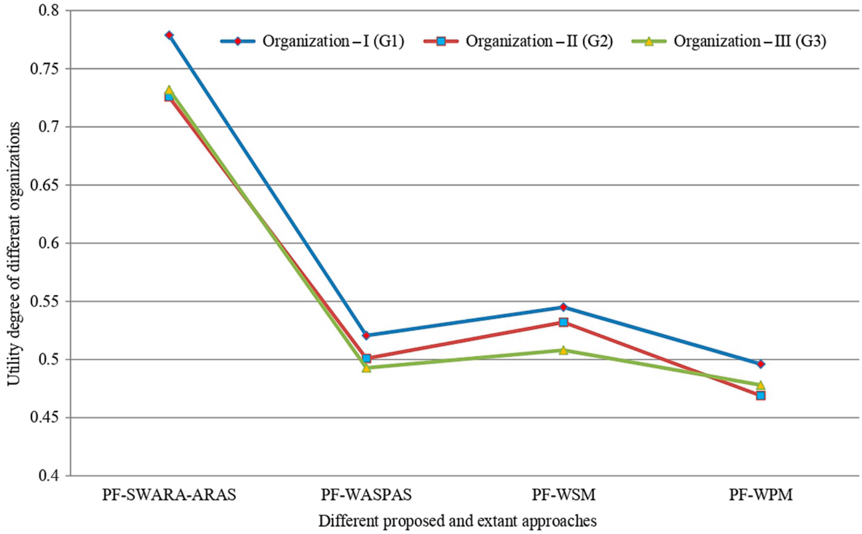

Figure 5. Comparison of utility degree of each organization to implement of G-IoT technologies with extant methods

Conclusions

This study mainly aimed to identify, rank, analyze, and evaluate the different challenges to implementing the G-IoT in sustainable development using an integrated fuzzy MCDM approach. At first, to recognize the important challenges to evaluate the G-IoT implementation, a survey study using the literature review and experts' opinions has been conducted. An ample framework including 23 challenges was discussed in regard to the implementation of G-IoT technologies for the development of a high sustainability level. In the next step, an integrated decision-making approach has been proposed to rank, analysis and evaluate the selected challenges using two important decision-making approaches, including SWARA and ARAS under Pythagorean fuzzy environment. In this study, to determine the accuracy of the experts' outlooks regarding the weights, the SWARA method was applied, and the ARAS approach was used to an optimal degree to evaluate the priority order of each alternative over a set of challenges.

In total, 23 challenges for the implementation of G-IoT technologies for achieving development of a high sustainability level were identified, which are routing for low-end devices, green architectures, reduction of CO_2 footprint of ICT, smart connected world, low range communication protocols, M2M standardization protocols, training of green communications, RFID technology, ZigBee standardization, IPV6 for low-end devices, green infrastructure, green networking, green spectrum management, green communication and connectivity, green service management, interoperability, complexity, and scalability, adaptation to natural energy sources, power management in the form of energy efficiency of ICT, data, computing, wireless networks, etc., information security and privacy protection, QoS provisioning, governance and legislation, and green policies and standardization.

The analysis results are found that; M2M standardization protocols with a weight value of 0.0508 are the most important challenges to implementing G-IoT technologies towards the SDAs. Adaptation to natural energy sources with weight value is the second most important challenge to implementing G-IoT technologies. Information security and privacy protection have the third place with a weight of 0.0469, IPv6 for low-end devices has a fourth-place with a weight of 0.0467, governance and legislation with weight 0.0458 has fifth most important challenge challenges to implement of G-IoT technologies, and others are considered crucial challenges to implement of G-IoT technologies towards the SDAs.

A case study of the manufacturing sector is taken to certify the rationality and applicability, and it is more flexible in solving the uncertain and qualitative inputs. This study identify the key challenges to implement the G-IoT as cutting-edge technology in the sustainable development perspectives; in this regard, further work can be investigated the role of different cutting-edge technologies like RFID, cloud computing, big data analytic, cybersecurity, autonomous robots, etc. in the area of sustainable development. Furthermore, this paper developed an integrated decision-making approach called PF-SWARA-ARAS; therefore, future works can develop several different kinds of MCDM models like gained and lost dominance score (GDLS), CoCoSo, etc., under various types of fuzzy sets, namely interval-valued fuzzy sets (IVFSs), interval type-2 fuzzy sets (IT2FSs), IFSs, and others types of fuzzy environment.

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