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A Fuzzy Expert System for Selecting Green Information Technology Strategy

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ABSTRACT

The pressure on Chief Information Officers (CIOs) to focus on Green Information Technology (GIT) has recently increased. However, many organizations still need to manage their environmental efforts due to a lack of strategic planning. This study aims to design a fuzzy expert system to suggest a proper GIT strategy for organizations, considering qualitative, obscure, and fuzzy factors. The study employs questionnaires distributed to experts to evaluate the factors that impact the level of GIT maturity using fuzzy logic. Based on the results obtained, a fuzzy expert system is designed to suggest a proper GIT strategy. The proposed expert system has been used at Alzahra University as a case study for selecting GIT strategies and activities. The findings suggest that Alzahra University should adopt a primary-level GIT strategy involving a three-year process of implementation, which includes actions such as removing old monitors, developing a green supply chain, reengineering organizational processes, disposing of useless ICT equipment in a green manner, and adopting green marketing practices. The fuzzy expert system designed in this study can help organizations adopt appropriate GIT strategies.

Keywords

Green information technology, Green information technology maturity, Green information technology strategy, Fuzzy expert system.

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1. Introduction

Air pollution and climate change are the most significant global environmental challenges. The increase in global temperatures, primarily caused by human-driven emissions of greenhouse gases into the atmosphere, can lead to severe environmental, societal, and economic consequences worldwide if temperature trends continue to rise (Santos et al., 2022). Parallelly, The growing world population and increasing use of renewable and non-renewable energy sources have led to a rise in greenhouse gases, pollution, and global warming. The demand for energy at various organizational levels has also increased, often accompanied by a need for IT systems. Unfortunately, over half of the energy produced is lost due to poorly designed systems and inefficient performance, resulting in hefty costs (Nishant et al., 2013). In today's fast-paced business world, organizations must adapt quickly to keep up. Information technology (IT) is critical in achieving efficiency and effectiveness in business models, governance, and waste management. Organizations are turning to Green IT as an alternative strategy to combat the negative environmental impact of technology. Green IT encompasses various topics such as green computing, e-waste, and organizational governance, aiming to reduce environmental impact, increase cost efficiency, and improve energy effectiveness (Nabila‘Aini and Subriadi, 2022).

One of the organizations' significant sources of greenhouse gas emissions is their information sources. However, these sources can also provide a key solution to reducing carbon emissions through green management. Information technology offers organizations excellent opportunities to improve their green performance, reduce costs, and increase revenue (Akman and Mishra, 2015). Green IT has become an active research field in information technology, and recent studies reveal that it has become a popular topic for researchers. Figure 1 shows the results of an analysis using VOSviewer software, a network visualization and analysis tool, on green IT studies found in Scopus. Figure 2 demonstrates that green IT has become a popular research topic in recent years in the Scopus database. (McAllister et al., 2022). Although GIT practices may not constitute a firm's core activities, such as manufacturing, supply chain, logistics, or service delivery, they reflect conscious and autonomous efforts to preserve environmental sustainability in IT practices. By adopting green IT practices, firms can use technology to meet the present generation's needs without compromising the ability to satisfy future generations' demands (Hu et al., 2022).

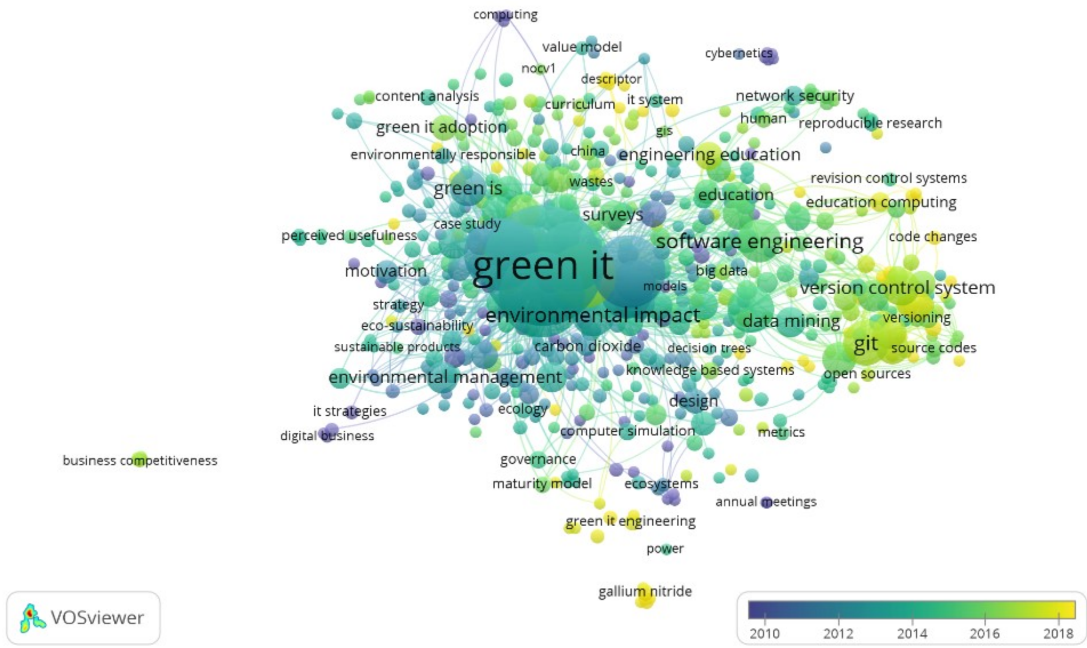

Figure 1. The keyword co-occurrence of GIT in scopus studies

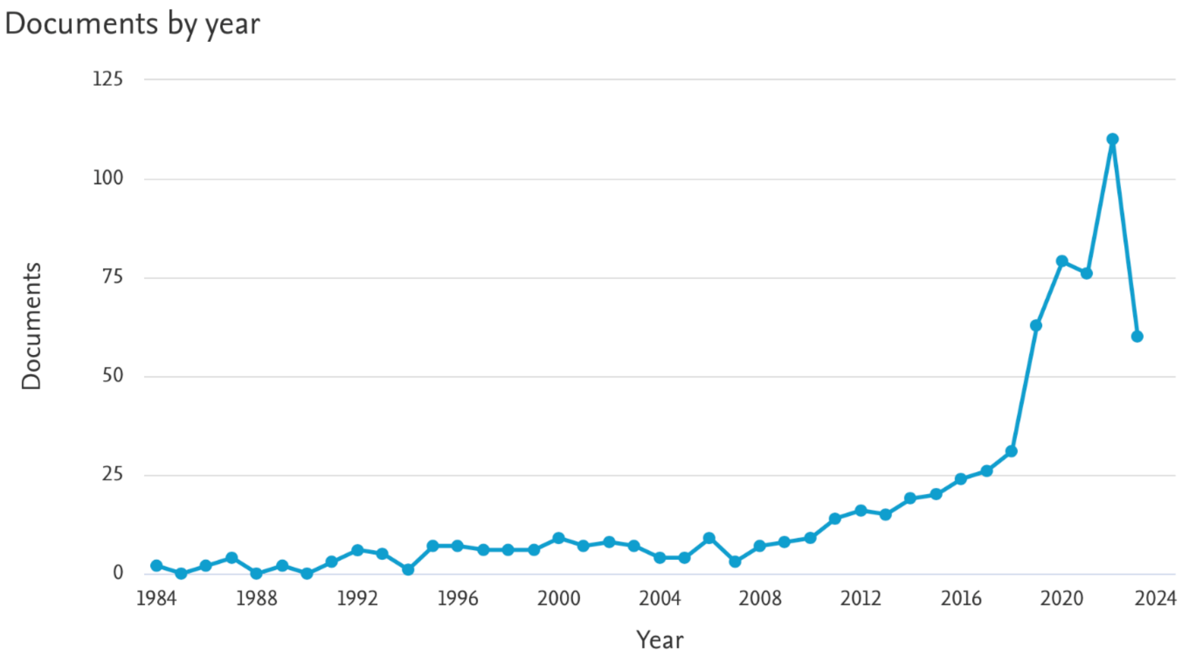

Figure 2. Research trend on GIT in scopus studies

Green IT strategies encourage organizations to take environmental responsibility by adopting long-term and consistent strategies (Asadi et al., 2015). Moreover, the rapid advancement of information technology (IT) has facilitated the wider adoption of environmentally friendly practices, supporting various technology-driven green initiatives. The swift growth of digital technology has been a key driver in bringing about significant changes in advancing the cause of the sustainable development field (Qu and Liu, 2022). As organizations increasingly rely on

IT, and IT itself relies on energy sources, it is crucial to use Green IT. Therefore, it is vital to identify and implement strategies that utilize green energies and improve environmental conditions. Different organizational factors affect GIT strategies. These factors can include both internal and external organizational factors. One of the most significant internal factors is the organization's maturity level in implementing green information technology. Previous studies have sporadically referred to factors that can influence the selection of green information technology strategies, but no model has been proposed for decision-making. Since most of these factors are qualitative and vague, and their impact on strategy is also vague and qualitative, this study proposes a fuzzy inference system for modeling this decision. In this study, the influential factors and their impact were extracted using the results of a questionnaire completed by experts in the field of green information technology, and based on these results, a fuzzy inference system was developed. The system's functioning entails organizations providing input regarding their internal and environmental attributes. Additionally, the system identifies the level of maturity of green information technology within the organization and proposes suitable strategies and corresponding actions.

2. Literature review

2.1. Green information technology (GIT)

Green IT (GIT) refers to the efficient and effective use of information and communication technologies (ICTs) in organizations to promote sustainable business practices (Deng et al., 2009). While there are multiple perspectives and definitions of Green IT, they all revolve around energy consumption and waste generation in the computer hardware and software domains (Zaman and Sedera, 2016). The core objective of GIT is to systematically apply environmental sustainability and clean technologies (Molla and Abareshi, 2011). It aims to reduce the environmental impact of IT operations by designing data centers and IT infrastructure that optimizes energy consumption and minimizes costs (Hernandez, 2020). It involves implementing energy-efficient hardware and software solutions, employing power management techniques, and utilizing virtualization and cloud computing technologies to consolidate servers and reduce energy usage.

Additionally, GIT addresses the issue of electronic waste (e-waste) generated by outdated or discarded IT equipment. It promotes responsible disposal, recycling, and refurbishment practices to minimize the environmental impact of e-waste. Organizations develop and adopt specific policies and strategies to achieve sustainable IT practices. These include sustainable procurement practices that consider IT products' energy efficiency and environmental attributes. Organizations also focus on optimizing data centers with energy-efficient cooling and power distribution systems, employing renewable energy sources, and implementing green software development practices.

Overall, GIT enables organizations to use resources sustainably in environmental and business contexts, aligning IT operations with sustainability goals and objectives (Loeser et al., 2017). By embracing Green IT, organizations can reduce their environmental footprint and improve operational efficiency and cost-effectiveness.

Table1. Factors affecting GIT strategy

Main factors	Sub-categories	Description	Reference
	Greenwashing aims	Greenwashing occurs when an organization conveys a false impression about its products, services, or brand	Taghva et al., (2017)
	Economic goals and saving financial resources	Economic goals aim to improve financial well-being. Saving financial resources is a way to achieve these goals and achieve financial security.	Taghva et al., (2017), Molla et al., (2009), Kazovsky et al., (2017), Unhelkar (2016) Atkinson et al., (2014)
	LESS consumption or production from environmental and not financial or operational perspective	Less consumption or production from an environmental perspective" refers to reducing the use of resources or minimizing waste and pollution to protect the environment, regardless of financial or operational considerations.	Molla et al., (2009), Hankel et al., (2014), Philipson (2010), Donnellan et al., (2011),
	EFFICIENCY	Improve work performance or better ways of doing work	Murugesan (2008), Molla et al., (2009), Forrest et al., (2008)
	OFFSET	Increase awareness and offset anything which may harm the environment	Taghva et al., (2017), Unhelkar and Tiwary(2011)
Green management policies of organization	Policies for changing and affecting staff attitudes (Awareness and positive attitude)	Awareness and positive attitudes of consumers and staff of an organization about carbon emission can significantly change how it works. This awareness should be institutionalized in the culture of the organization.	Taghva et al., (2017), Unhelkar (2016), Su and Al-Hakim (2010), Jenkin et al., (2011)
	Policies on proper disposal of the waste, equipment sans toxic materials	Policies on proper disposal of waste and equipment without toxic materials refer to established guidelines for safely and environmentally friendly discarding of waste and devices that do not contain harmful substances.	Atkinson et al., (2014) Su and Al-Hakim (2010), Britt et al., (2019) AlHarbi and Pattinson (2016)
	Policies for purchasing green equipment and the related services	Policies for acquiring environmentally friendly equipment and associated services" refer to established guidelines for procuring equipment and services that prioritize environmental sustainability and reduce ecological impact.	(Halchin et al., 2010) (Dedrick, 2010)
	Policies for accepting and implementing recyclable equipment	A policy of accepting and implementing the recycling of equipment recycles the materials that can be reused; it delays the replacement of active equipment and increases awareness about how to reuse the equipment.	Unhelkar (2016), Su and Al-Hakim (2010), Murugesan (2008)
	Policies for optimizing energy consumption in organizational procedures	Policies for efficient energy use in organizational processes" refer to those established to minimize energy consumption and improve efficiency within an organization's operations.	Nanath and Pillai (2017) (Atkinson et al., 2014)

Main factors	Sub-categories	Description	Reference
	Policies for using renewable energies (solar, nuclear energy)	Policies for utilizing renewable energies refer to established guidelines for adopting and responsible use of sustainable energy sources like solar power and nuclear energy within an organization's operations.	Melville (2010), Faucheux and Nicolaï, (2011), Du et al., (2023)
	Compensatory measures	Make up the negative environmental impacts by taking compensatory measures to improve bad environmental conditions.	Taghva et al., (2017), Unhelkar and Tiwary(2011)
Individuals	Leader	A leader guides, directs, and inspires others towards a common goal or vision.	Dao et al., (2011), Unhelkar (2016), Atkinson et al., (2014)
	Employees	Employees are individuals hired by an organization to perform specific tasks or duties in exchange for compensation.	Unhelkar (2016), Murugesan (2008), Atkinson et al., (2014),
	Beneficiaries	Beneficiaries and shareholders support new IT plans, ideas, and opinions to make improvements.	Dao et al., (2011), Tokkozhina et al., (2023), Corbett (2010), Molla et al., (2009)
Structural elements	Capacities	Capacities refer to an individual, organization, or system's abilities, skills, resources, and potential to achieve a particular goal or objective.	Corbett (2010), Unhelkar (2016), Melville (2010), Taghva et al., (2017)
	Structure	Structure refers to the organization, arrangement, and framework of a system, organization, or entity.	Melville (2010)
	Organizational processes	Organizational processes refer to the series of steps or activities an organization takes to achieve its objectives.	Dao et al., (2011),)Unhelkar (2016), Donnellan et al., (2011), Murugesan (2008)
	Economic factors and budgeting	Economic factors impact the production, distribution, and consumption of goods and services, while budgeting involves planning and allocating financial resources to achieve specific goals.	Faucheux and Nicolaï (2011), (Dedrick, 2010), Molla et al., (2009), Tokkozhina et al., (2023), Corbett (2010), Zheng, (2013), Nanath and Pillai (2017)
Social, cultural environmental factors	Environmental values Beliefs and trends Social responsibility External, natural and artificial resources of organization Demolition and productivity rate of resources	Environmental values refer to the beliefs, attitudes, and principles that individuals and society hold regarding protecting and preserving the natural environment. Beliefs are ideas or convictions about reality shaped by cultural, social, or personal factors. Trends are the direction or pattern of change in a particular area over time. Social responsibility is the ethical obligation of individuals, organizations, and businesses to benefit society and the environment through practices. External resources come from outside sources like suppliers, customers, or partners. Natural resources are materials or substances that occur naturally and are used by organizations. Artificial resources are tools, machinery, or technology organizations use to facilitate operations and achieve goals. Demolition is the act of destroying a building or structure. The productivity rate of resources is the efficiency with which an organization or individual uses their resources.	Taghva et al., (2017),) Unhelkar (2016), Su and Al-Hakim (2010), Jenkin et al., (2011), Jailani et al., (2016), Molla et al., (2009), Forrest et al., (2008), Dalvi-Esfahani et al., (2020)
Marke	Special standards	These factors reflect the impact of current standards, obligatory rules and regulations, and various	Murugesan (2008), Nanath and Pillai (2017),

Main factors	Sub-categories	Description	Reference
		pressures from the market and environmental pressures on organizations, people, and corporate measures.	Atkinson et al., (2014) Donnellan et al., (2011), Halchin et al., (2010)
	Rules and regulations	Rules and regulations refer to established guidelines or directives that govern behavior, actions, or procedures within a specific context, such as an industry, organization, or society.	Faucheux and Nicolaï (2011), Taghva et al., (2017), Su and Al-Hakim (2010), Jenkin et al., (2011), Unhelkar (2016), Donnellan et al., (2011)
	Market pressure	Market pressure refers to the forces or factors that influence the behavior and decisions of buyers, sellers, and other participants in a market.	Unhelkar (2016), Su and Al-Hakim (2010), Jenkin et al., (2011)
Technological factors	Technological infrastructure and available technologies	Technological infrastructure refers to the underlying hardware, software, and networks that support the use of technology in an organization or society.	Unhelkar (2016), Taghva et al., (2017), Su and Al-Hakim (2010), Jenkin et al., (2011)
	Hardware (network, data center, and monitors)	Hardware refers to the physical components of a computer or electronic device, such as the central processing unit (CPU), memory, hard drive, keyboard, and monitor.	
	Environmental intelligence	Environmental intelligence is the capacity of people and organizations to comprehend and tackle environmental problems.	
Maturity level of an organizatio	Data center	The data center is responsible for assessing the physical equipment, server property, and infrastructure support to evaluate capital management procurement, capital expenditure, and operating expenditure.	

2.2. Green IT maturity model

Organizations often rely on maturity models to enhance business processes and effectively manage sustainability initiatives. However, it is crucial to complement these models with sustainability performance assessment tools to gain deeper insights into sustainability concerns and develop effective improvement plans. These tools enable organizations to evaluate their sustainability practices against industry benchmarks and best practices, facilitating the identification of areas for improvement and creating a roadmap to achieve sustainability goals. By leveraging assessment tools, organizations can bridge gaps and enhance their sustainability practices to meet the growing demand for sustainable business operations (Sohns et al., 2023). One widely used assessment tool in creating Green IT is the maturity model. This model encompasses various techniques and processes to guide organizations in developing mature green information technology practices. It evaluates different aspects of an organization's operations, behaviors, and accomplishments. To provide a comprehensive report, the model conducts a detailed analysis of each department separately, closely examining the organization's internal functions (Desai, 2014). Green IT models function as assessment and measurement tools, providing organizations with a clear roadmap to follow (Foogooa et al., 2015).

The Green IT maturity model allows organizations to assess their current level of sustainability practices, identify strengths and weaknesses, and prioritize areas for improvement. It covers energy efficiency, waste management, sustainable procurement, data center optimization, and green software development. This model allows organizations to evaluate performance, set targets, implement strategies, and monitor progress toward sustainable IT practices within a structured framework. Furthermore, the Green IT maturity model enables organizations to benchmark themselves against industry peers and best practices. This benchmarking process allows organizations to set realistic goals and track their sustainability performance over time. The model guides organizations through different stages of maturity, from initial implementation to advanced and innovative practices, providing a systematic approach to enhancing sustainability practices.

In conclusion, the Green IT maturity model and sustainability performance assessment tools empower organizations to evaluate, improve, and monitor their sustainability practices effectively. By leveraging these tools, organizations can align their IT operations with sustainability goals, reduce environmental impact, and contribute to their business's overall sustainability and success.

3. Methodology

The purpose of this study is applied-developmental, as it aims to evaluate the factors that influence the level of green IT maturity. In order to accomplish this objective, questionnaires were disseminated to collect pertinent data and evaluate professionals' perspectives. A fuzzy expert system was designed to suggest an appropriate green IT strategy based on the results obtained. The system was tested and implemented at Alzahra University for selecting the appropriate GIT strategy. The tool used for data collection is a questionnaire. The study framework comprises several steps, which are illustrated in Figure 3. Overall, this research is a practical guide for organizations looking to improve their green IT maturity level and implement effective sustainability strategies.

Step 1: The problem addressed in this study is selecting an appropriate green IT strategy for an organization. Decision-makers should consider various internal and external factors, such as the capacity and readiness of people, organizational structure, green IT maturity level, and technological factors. These factors were identified and examined through a literature review, and the findings are presented in Table 1.

Step 2: After identifying the problem and relevant factors, rules were established to make inferences based on the findings. In order to ascertain the authenticity of the regulations, questionnaires were devised and disseminated to professionals in the field of information technology to solicit their viewpoints. Based on the results obtained from the experts' responses, the rules were edited, and a fuzzy expert system was designed.

The results obtained from the expert questionnaire are presented in Table 2. This table‘s sub-criteria correspond to the identical subcategories delineated in Table 1. Within this context, we have furnished the mean evaluations derived from expert assessments for each subcategory and the notation employed for these evaluations within the MATLAB environment.

Step 3: In this step, the designed fuzzy expert system was used to select a green IT strategy for Alzahra University. This step is a practical demonstration of how the fuzzy expert system can be used to select an appropriate green IT strategy for an organization.

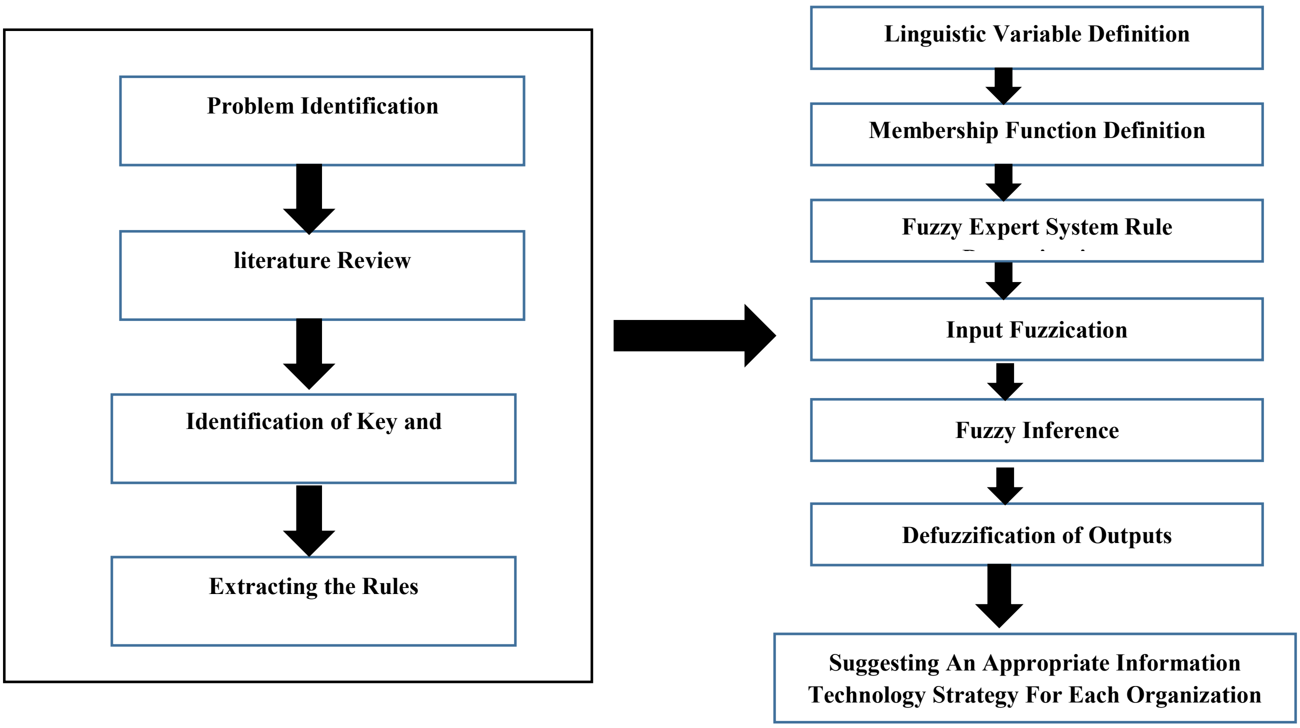

Figure 3. The research framework

Table 2. Average experts' responsiveness regarding key system criteria

Sub-criteria (Notation in MATLAB)	The average responses of experts	Sub-criteria (Notation in MATLAB)	The average responses of experts
Reducing the amount of energy consumed by the organization **(V1)**	0.75	Reducing the operational cost of the organization **(V2)**	0.68
Social acceptability **(V3)**	0.9	Implementation of rules and regulations **(V4)**	0.83
Income and profitability **(V5)**	0.5	Reducing carbon footprint **(V6)**	0.89
Sustainability of resources **(V7)**	0.79	Organizational sustainability **(V8)**	0.61
Environmental survival **(V9)**	0.67		
Average level of green information technology strategy based on objectives Green organization (OO)			0.5
Proper disposal of waste equipment and toxic materials **(V1)**	0.58	Impact on employees' views **(V2)**	0.86
Optimizing energy consumption in organizational processes **(V3)**	0.79	Implementation of recyclable equipment **(V4)**	0.52
Green equipment and related services **(V5)**	0.57	Renewable energies **(V6)**	0.12
compensatory measures **(V7)**	0.23		
Average level of green information technology strategy based on organizational policies (OE1)			0.5
The amount of participation and influence leadership **(V1)**	0.75	The amount of participation and influence Employees **(V2)**	0.5
The amount of participation and influence Beneficiaries **(V3)**	0.5	priorities for people's involvement in green information technology projects **(V4)**	0.67
The average level of green information technology strategy based on the level of participation and influence of people (VP)			0.58
knowledge and awareness **(V1)**	0.6	ability **(V2)**	0.6
Support and support **(V3)**	0.86	Desire and interest **(V4)**	0.83
risk taking **(V5)**	0.19		
Average level of green information technology strategy based on participation and leadership influence (P1)			0.75
Positive outlook and approach **(V1)**	0.83	Related education **(V2)**	0.22
ability **(V3)**	0.21	Teachability and learning **(V4)**	0.6
Average level of green information technology strategy based on employee participation and influence (O1)			0.5
knowledge and awareness **(V1)**	0.41	Interest and desire **(V2)**	0.65
Support and support **(V3)**	0.53	ability **(V4)**	0.45
risk taking **(V5)**	0.6		
The average level of green information technology strategy based on the level of participation influence of stakeholders (P2)			0.5
The level of the organization's capabilities **(V1)**	0.5	Internal structure level **(V2)**	0.25
The level of organizational processes **(V3)**	0.5	Level of financial resources and budget **(V4)**	0.65
The average level of green information technology strategy according to organizational structure factors (CC1)			0.5
The degree of flexibility and change in the organization **(V1)**	0.4	The extent of process redesign **(V2)**	0.83
Changing the culture in the organization **(V3)**	0.39	The power of promotion in front of the shareholders **(V4)**	0.81
Bargaining power against suppliers **(V5)**	0.83	Comprehensive map planning **(V6)**	0.34
Average level of green information technology strategy based on capabilities (P3)			0.5
Dominant and strong support group **(V1)**	0.38	Dedicated resources for project implementation **(V2)**	0.41

Sub-criteria (Notation in MATLAB)	The average responses of experts	Sub-criteria (Notation in MATLAB)	The average responses of experts
Appropriate educational structure **(V3)**	0.22	Independent consultation **(V4)**	0.43
Evaluation and audit system **(V5)**	0.15		
Average level of green information technology strategy based on internal structure (P4)			0.25
Coordination between the processes of the organization **(V1)**	0.34	The possibility of implementing green process management **(V2)**	0.5
Business process modeling **(V3)**	0.76	process optimization **(V4)**	0.18
Process Performance Reporting **(V5)**	0.42		
Average level of green information technology strategy according to organizational processes (CC2)			0.5
Allocated budget level **(V1)**	0.65	Expected rate of return on investment **(V2)**	0.4
Investment time frame **(V3)**	0.5		
Average level of green information technology strategy based on financial and economic issues (CC3)			0.65
Environmental values **(V1)**	0.41	Adherence to the beliefs and trends of green information technology **(V2)**	0.52
The organization's commitment to social responsibility **(V3)**	0.93	External, natural and artificial resources available to the organization **(V4)**	0.67
The rate of resource destruction **(V5)**	0.6		
Average level of green information technology strategy by issues Environmental social and cultural (CC4)			0.735
Organizational specific standards in line with green information technology **(V1)**	0.4	Government rules and regulations in line with green information technology **(V2)**	0.2
Market pressure in the direction of moving towards green information technology **(V3)**	0.19		
Average level of green information technology strategy based on regulatory market factors (CC5)			0.238
Information technology infrastructure and available technologies **(V1)**	0.54	Hardware provided **(V2)**	0.5
Environmental intelligence **(V3)**	0.4	Green IT specialists **(V4)**	0.8
Integration of information systems **(V5)**	0.4		
Average level of green information technology strategy based on technological factors (CC6)			0.5
Basic application of server virtualization solutions **(V1)**	0.42	Using orchestration tools **(V2)**	0.2
Optimal use of server instances **(V3)**	0.2	Server performance **(V4)**	0.44
Electrical efficiency **(V5)**	0.32	Storage integration **(V6)**	0.42
Management of storage equipment using indicators **(V7)**	0.20	Network convergence **(V8)**	0.42
Intelligent power allocation management **(V9)**	0.4	Separate platform integration support **(V10)**	0.33
Timely monitoring of electricity consumption **(V11)**	0.8	Efficient design **(V12)**	0.37
DC efficient in energy consumption **(V13)**	0.41	Automation of temperature and humidity control **(V14)**	0.2
Center Green IT Maturity Score (DC)			0.25
Disable the screen saver **(V1)**	0.15	Power control using the power management system of IT tools **(V2)**	0.41
Replacing desktops with laptop computers **(V3)**	0.2	Using thin client solutions **(V4)**	0.4
Cut off power for tools that are not in use **(V5)**	0.76	Use of multifunction printing tools **(V6)**	0.88
Using virtual fax services **(V7)**	0.67	Use toner saving solutions **(V8)**	0.62
Automating power cuts at night and on holidays **(V9)**	0.4	Integration of print management services **(V10)**	0.56

Sub-criteria (Notation in MATLAB)	The average responses of experts	Sub-criteria (Notation in MATLAB)	The average responses of experts
Wireless network instead of fixed line network **(V11)**	0.42	Intelligent lighting systems **(V12)**	0.4
Energy efficient lighting systems **(V13)**	0.36	Automation of temperature control **(V14)**	0.8
Power cuts at night and on holidays **(V15)**	0.8		
Office Environment Green IT Maturity Score (OE2)			0.5
Work processes that are done electronically **(V1)**	0.78	Electronic verification system **(V2)**	0.78
Online real-time transactions in providing services to customers **(V3)**	0.4	Implementation of the Internet organization system **(V4)**	0.79
Issuing invoices (or payment receipts) for customers using an electronic system **(V5)**	0.41	Programs that conform to rational principles (a specific program to reduce the size of your application portfolio and achieve a unified standard architecture) **(V6)**	0.4
Durability and improvement of processes **(V7)**	0.2	Using integrated communication tools **(V8)**	0.46
Use of video conferencing systems (V9)	0.37	Support and encourage remote communication **(V10)**	0.21
Ability to support in the form of remote services **(V11)**	0.4	Training green technology to employees (V12)	0.4
Environmental impact analysis **(V13)**	0.4	Costing systems for IT services **(V14)**	0.33
The costing mechanism of carbon costs released for units or projects **(V15)**	0.4	enterprise resource planning system (ERP) **(V16)**	0.37
Business Activity Green IT **Maturity Score (WP)**			0.5
IT assets **(V1)**	0.18	Database configuration management (CMDB) **(V2)**	0.21
Linking the database configuration management)CMDB (with the relevant catalog service **(V3)**	0.14	Using information technology tools and equipment that are efficient in terms of energy consumption **(V4)**	0.41
Consider carbon emissions when purchasing new assets **(V5)**	0.48	The existence of policy and rules required to use products in accordance with environmental laws and regulations **(V6)**	0.23
Use of intelligent logistics systems **(V7)**	0.10	Minimize the use of consumables **(V8)**	0.34
Use of environmentally friendly office products **(V9)**	0.42		
Maturity of green IT **based on logistics (P5)**			0.25
Management of toxic and hazardous materials on materials that are sold or discarded **(V1)**	0.43	Incentives and rewards offered to employees to reduce waste **(V2)**	0.23
Efforts to reduce environmental impact **(V3)**	0.41	Reusing waste water and thermal waste from offices and IT resources **(V4)**	0.12
Existence of an incentive program for the participation of employees in environmental movements **(V5)**	0.28	Use of intelligent redundancy **(V6)**	0.36
Electronic distribution of customer / vendor brochures **(V7)**	0.81	Rules required for reuse of assets **(V8)**	0.14
Reuse of consumables **(V9)**	0.21		
Corporate Citizenship Green IT **Maturity Score (CC7)**			0.5
Maturity level of green information technology			0.5
Appropriate level of hybrid system green information technology strategy			0.5

3.1. Conceptual model

When designing the conceptual model for a hybrid expert system, it is essential to consider the significant research criteria, including their sub-criteria. The inputs for the fuzzy expert system comprise various factors, such as green objectives, the collaborative capacity of people, green management policies, and technological, environmental, socio-cultural, structural, market regulatory, and corporate maturity levels. The system represents these factors as linguistic variables, such as very poor, poor, average, good, and excellent. The system output is the most appropriate green IT strategy for the organization.

Then, the system rules were designed and placed in the inference engine to build the system's knowledge base. A field-type fuzzy inference was used for the system production. The conceptual model of the research has been presented in Figure 4 hierarchy levels.

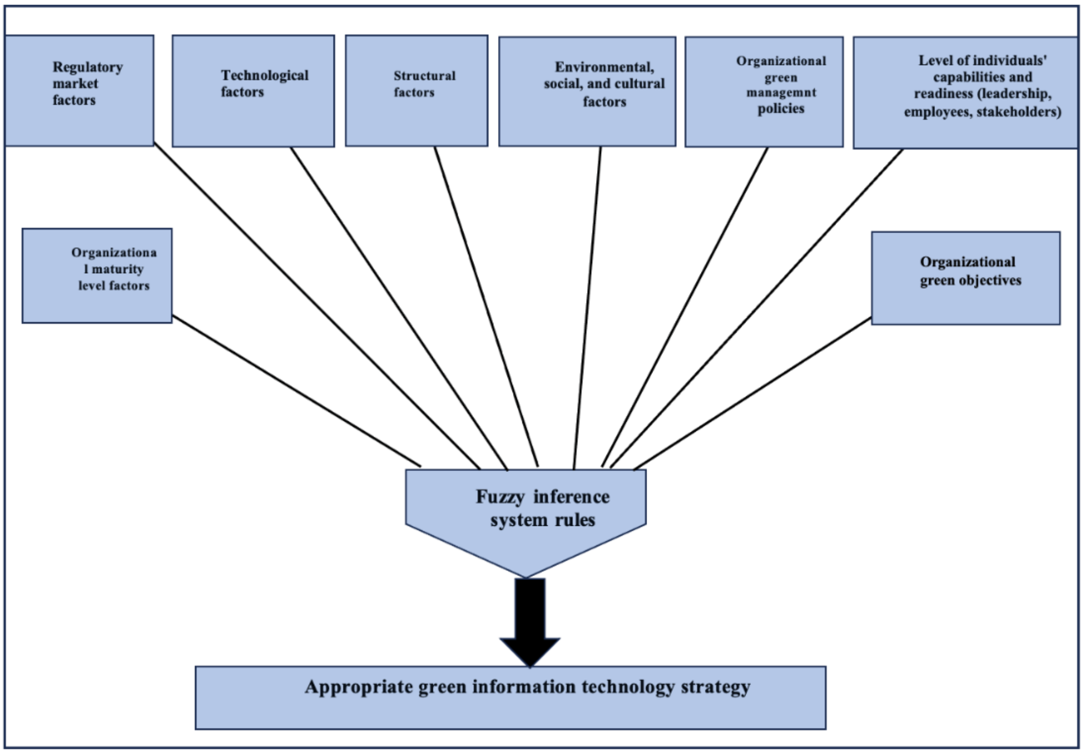

Figure 4. A conceptual research model for selecting green information technology strategies

3.2. System architecture

This study involved designing an expert system for each significant criterion identified, which was then integrated to form a single hybrid expert system. The output of each subsystem served as the input for the hybrid system, and the output of the hybrid system was the appropriate green IT strategy for the organization.

The hybrid expert system was designed to address organizational challenges in precisely calculating sub-criteria. It is often easier for organizations to calculate the weights of primary criteria, which are generally more applicable in organizations that use information technology. Therefore, a hybrid system that can calculate the output separately by averaging the input scores is more efficient and applicable than a single-payer system.

4. Result

The system was designed using the Fuzzy Logic Toolbox in MATLAB. The system's fuzzy membership functions, intervals, and rule base were designed using MATLAB. The input criteria are listed in Table, and the output is the Green IT strategy level. The Mamdani fuzzy inference system was used to design the system, with triangular and Gaussian functions used as membership functions and the Centroid method used for defuzzification. The proposed system has a two-tier architecture, with 120 inputs introduced to 8 independent fuzzy systems.

4.1. System 1: Corporate green objectives system (factors related to the organization's green objectives).

System input: Reduced operational costs of the organization, fake labels and false claims, false suggestions in catalogs and websites, increased or maintained sales by using green labels, reduced energy consumption in the organization, improved reputation and popularity of the organization (social acceptance), observation of government rules and regulations, increased revenue and profitability of green IT plans, the reduced carbon footprint of the organization and its negative effects on the environment, resource sustainability objectives and improved environmental conditions, environmental survival for future generations and related considerations, green social responsibility, compensatory measures to reduce negative effects on the environment, and carbon credit purchase.

System output: The corporate level of green objectives (concerning factors influencing the Green IT strategy level) depends on applying Green IT. Figure 5 shows the corporate objectives system.

Figure 5. Corporate objectives system

4.2. System 2: Green management policy system (factors related to green management policies of the organization).

System input: Proper disposal of waste, equipment, and toxic materials, reception and implementation of recyclable equipment, delay in replacement of active equipment, increased awareness about reusing equipment, optimized energy consumption in organizational processes, the influence of employee attitudes, green equipment, and relevant services, enforcement of EPAT and Energy Star standards at federal, state, and local levels, use of renewable energies (solar, nuclear), and taking compensatory actions to improve bad environmental conditions.

System output: The alignment of organizational green management policies and Green IT (from a set of factors influencing the Green IT strategy level) depends on applying Green IT.

4.3. System 3: System of capacity and the extent of people's participation in the organization (factors related to capacity and people's participation).

System input: Inputs of this system include leaders, employees, and beneficiaries, and the organization prioritizes people's broad participation.

System output: The effectiveness level is people's capacity and participation to implement Green IT strategies in the organization.

4.3.1. Sub-system: Leader capacity and participation sub-system.

System input: Leader's support for new IT plans as well as new opinions and ideas to make improvements, enabling the leader to create a dynamic environment to accept and implement Green IT plans, the leader's knowledge of new science, promotion of knowledge and updating of IT knowledge consistently, the leader's knowledge of ongoing affairs in line with new science and technology and IT, the leader's interest and tendency to search for new technologies and apply them in major and vital activities of the organization, the leader's risk-taking to implement IT and new technologies for the first time as a pioneer, and beneficiaries and shareholders' cooperation with the Green IT executive team.

System output: The effectiveness level is considered the leader's capacity and participation in implementing Green IT strategies.

4.3.2. Sub-system: Employees' capacity and participation sub-system.

System input: Employees' capacity to implement new IT plans, employees' education, ability to pick up training and learn Green IT plans, and employees' environmental orientation. *System output*: The employees' capacity and participation level align with the organization's Green IT strategy implementation.

4.3.3. *Sub-system: Beneficiaries' capacity and participation sub-system.*

System input: Beneficiaries' and shareholders' support for new IT plans, ideas, and opinions to make improvements; beneficiaries' and shareholders' ability to provide a dynamic environment to accept and implement Green IT plans; beneficiaries' and shareholders' knowledge of new science, enhancement of knowledge and updating of IT knowledge consistently; beneficiaries' and shareholders' knowledge of ongoing affairs in line with new science and technology and IT, beneficiaries' and shareholders' interest and tendency to search for new technologies and apply them in significant and vital activities of the organization, and beneficiaries' and shareholders' risk-taking to implement IT and new technologies for the first time as a pioneer.

System output: The beneficiaries' capacity and participation level align with the organization's Green IT strategy implementation.

4.4. System 4: Organizational structure system (factors related to organizational structure).

System input: This system consists of four sub-systems as input, which include capacities, internal structure, processes, economic factors, and budgeting.

System output: The level of the organizational structure's alignment with the Green IT strategy (from a set of factors that influence the Green IT strategy level) depends on applying Green IT.

4.4.1. *Sub-system: Capacities sub-system*

System input: Capacities such as knowledge and understanding of Green IT, staff size and capability, and the number of qualified personnel in Green IT.

System output: The organization's capacity level in Green IT implementation.

4.4.2. *Sub-system: Internal structure sub-system*

System input: Internal structure factors such as the level of communication between different departments and levels of the organization, the level of flexibility in the organization's structure, the level of decentralization, and the level of autonomy in decision-making. *System output*: The level of the organization's internal structure alignment with the Green IT strategy.

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4.4.3. Sub-system: Processes sub-system

System input: Process factors such as the level of coordination between different processes, the level of automation in processes, and the level of documentation and record-keeping in processes.

System output: The synchronization of organizational processes with the Green IT strategy.

4.4.4. Sub-system: Economic factors and budgeting sub-system

System input: Economic and budgetary factors encompass the allocation of funds towards Green IT, the level of financial support for Green IT initiatives, and the return on investment in Green IT.

System output: The level of alignment of economic factors and budgeting with the Green IT strategy.

4.5. System 5: Economic, social environmental factors (cultural, social environmental factors.

System input: Green IT practices such as the level of energy-efficient equipment use, virtualization, electronic document management, telecommuting and videoconferencing, server consolidation, data center consolidation, and level of cloud computing use.

System output: The alignment of Green IT practices with the Green IT strategy.

4.6. System 6: Market regulatory factors system (factors related to market regulation).

System input: Market pressures, government legislation, and organizational norms that support green IT.

System output: Influential market regulatory factors in line with green IT strategies.

4.7. System 7: Technological factors system (organizational technology-related factors).

System input: The extent of the organization's environmental consciousness, the level of hardware accessibility, the information technology infrastructure, and the level of integrated information systems.

System output: Capacity of technological factors in line with green IT strategies.

4.8. System 8: Green IT maturity system (green it maturity-related factors)

System input: This includes five subsystems of data center, administrative environment, organizational citizenship, and procurement.

System output: Assess the organization's final score of green IT.

4.8.1. Subsystem: Data center system

System input: Application of server virtualization solutions, the initial application of server virtualization solutions, using orchestration tools, optimal use of server samples, server function, electrical efficiency, storage integration, storage devices management using indicators, network convergence, smart power allocation management, integration of separate platform to support, on-time electricity consumption monitoring, designing an energy-efficient data center, automate the temperature and humidity control, planning according to logical data center principles.

System output: Green IT maturity level concerning the data center.

4.8.2. Subsystem: Administrative environment system

System input: Disable screen saver, power control using the system of power management of IT devices, replace desktop PCs with laptops, use a client IT solution, cut the power to unused devices, use multifunction print devices, use virtual fax services, use toner-saving solutions, automate power cut at night and holidays, integrate printing management services, use a wireless network instead of a landline network, smart lighting systems, energy-efficient lighting systems, automated temperature control, a power outage at night and holidays.

System output: Level of green IT maturity concerning the administrative environment.

4.8.3. Subsystem: Work activities system

System input: Electronic work processes, electronic confirmation systems, online real-time transactions to provide service for customers, issue invoices (or receipts) to customers through an electronic system, rational programs (specific plans to reduce application portfolio size to achieve an integrated standard architecture), process durability improvement, use integrated communication tools, use video conferencing tools, support and encourage remote communication, ability to support through providing remote services, teach green technology to employees, environmental impact analysis, costing systems for IT services, costing mechanism to find carbon emission cost for units or projects, the system of planning organizational resources.

System output: Green IT maturity level concerning work activities.

4.8.4. Subsystem: Procurement system

System input: Efficient IT asset replacement cycle, data center configuration management, linking of data center configuration management to the relevant catalog service, use of energy-efficient IT devices and equipment, considering carbon emission when purchasing new assets, set policies and rules to use products according to environmental rules and regulations, use logistic intelligent systems, minimize the use of consumables, use environmentally-friendly office products.

System output: Green IT maturity level concerning procurement.

4.8.5. Subsystem: Organizational citizenship system

System input: Management of hazardous and toxic materials that are sold or disposed of, employee rewards and incentives to reduce waste, efforts to reduce environmental impacts, reuse wastewater and thermal waste of IT resources and offices, incentive programs to involve employees in environmental movements, deploy smart redundancy, electronic distribution of customer/seller brochures, rules required for asset reuse, reuse consumables.

System output: Green IT maturity level concerning organizational citizenship.

4.9. Final synthetic system: Green IT strategy system

System input: Outputs of the former 8 systems are defined as inputs for this system. System output: Green IT strategy level.

Overall, these individual systems are integrated to generate a comprehensive Green IT strategy level. The output of each system is used as an input to the next system. The overall output of the system is the Green IT strategy level, which measures the organization's level of alignment with Green IT strategies and practices. The proposed system can help organizations assess their current level of alignment with Green IT and identify areas for improvement to implement Green IT strategies effectively.

5. Fuzzy system membership functions

A fuzzy set is defined by its membership function, where each element of X is mapped to a value between 0 and 1, and each member has a degree of membership. The membership function of a fuzzy set X is a function of X between 0 and 1. The membership function of X represents the fuzzy subset of X. The membership function of a fuzzy set A is usually represented as μA. For each element of X, the degree of μA(x) is called the membership degree of X in the fuzzy set A (Zheng, 2013).

Functions of trapezoidal fuzzy numbers can be calculated in MATLAB according to the following equation:

$$f(x;a,b,c,d) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases} \quad (1)$$

$$\mathrm{f(x;a,b,c,d)} = \max(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0) \quad (2)$$

Table 1 provides fuzzy numbers for the fuzzy IT strategy system and the related sub-systems.

Table 1. Fuzzy numbers of systems

Fuzzy membership function values	Variable intervals	Type of membership function
Very poor (-0.225, -0.025, 0.025, 0.225) Poor (0.025, 0.225, 0.275,0.475) Average (0.275, 0.475, 0.525, 0.725) Good (0.525, 0.725, 0.775, 0.975) Excellent (0.775, 0.975, 1.025, 1.225)	(0, 1)	Trapmf

6. Hybrid fuzzy expert system

In this study, considering the important effects of the criteria, some rules were omitted, and 12 rules were set for each sub-system. As the number of rules is multiplied by each other in the synthetic system, it resulted in more than 100 rules, which is an appropriate number for designing an expert system. The results of testing the system would confirm this. The input to the system is the final synthetic fuzzy system, and the output is the proposed green IT strategy level. The fuzzy inference system applied in this study is Mamdani. The center of gravity was used for defuzzification, and the Max function was used for the union of fuzzy sets. Figure 6 shows some fuzzy inference system rules.

Figure 6. The final synthetic fuzzy inference system

6.1. Examining the system function using sensitivity analysis of variables

In order to test the model, the output behavior analysis method was used, which involves fixing the values of all input variables except one and then increasing or decreasing the value of this variable. For each increase or decrease in inputs, the value of each output was calculated by the expert system, and the resulting behavior was analyzed. If the output-input behaviors are consistent with expert opinions and literature review, the credibility of the expert system is confirmed. Otherwise, the system must be improved. The relevant literature confirmed the expert system output in this research. Each output was measured using MATLAB.

6.2. Testing the system's performance at Alzahra University

Alzahra University was selected as the case study to evaluate the system's performance. Five experts in green information technology were asked to complete questionnaires based on the criteria of the fuzzy expert system, and the average response rate was measured for each criterion. These values were then entered into the system to propose an appropriate green IT strategy for the university. After computing the organization's green IT level, the appropriate strategy level was determined, and suggestions were made to improve the GIT level. The findings suggest that Alzahra University should adopt a primary-level GIT strategy involving a three-year process of implementation, which includes actions such as removing old monitors, developing a green supply chain, reengineering organizational processes, disposing of useless ICT equipment in a green manner, and adopting green marketing practices.

7. Discussion and conclusion

This study aimed to identify and classify the factors that are effective in selecting a green IT strategy. Based on the identified factors and knowledge obtained from experts, an expert system was designed to propose a green IT strategy. The system was evaluated using a sensitivity analysis of variables and a case study at Alzahra University. The results obtained from implementing the system at Alzahra University indicate that the proposed strategy for the university is at the middle level (primary strategic strategy). This organization thoroughly considers the factors that significantly influence the formulation of the ultimate strategy. Nevertheless, should a non-systematic approach be employed, the practicality of comprehensively considering all these factors concurrently could be severely limited. Conversely, over various time intervals, the organization can refine its strategy using the devised system, and in contrast to alternative methods, this capability might be unattainable.

The study findings suggest that Alzahra University should engage in a three-year implementation process to advance its green IT objectives. During this period, organizational processes should be reengineered, old monitors should be removed, a green supply chain should be developed, unusable Information and Communication Technology (ICT) devices should be disposed of and buried, and green marketing should be established as the core organizational process.

The expert system designed in this study can be used by all industries producing green products and information technology. It can provide tools to evaluate organizations' current condition and readiness for green IT. It allows them to identify their green IT level, make strategic decisions regarding changing their organizational level, and determine how much to invest in green IT. The utilization of a fuzzy approach in this article for modeling rules provided us with the capability to account for the influence of qualitative and ambiguous variables in the final decision-making process, representing one of the innovations of this paper.

It is suggested that the indicators used in Iran and other countries be reconsidered and that the system rules be modified, as these indicators may vary based on geographical conditions, government rules, frameworks, and requirements necessary to implement information technology in different countries. It may improve the efficiency of the fuzzy expert system.

This study has some limitations that should be taken into consideration. For example, the way the research was evaluated and the criteria used to assess its novelty may not have been comprehensive enough, which could impact the results' accuracy. Additionally, there is no established maturity model in Iran to compare with, and there is not much literature on selecting green IT strategies. The researcher had limited access to resources, meaning they had to rely on online sources to gather information. Lastly, there are few studies available in this field, which could make it difficult to compare the results of this research with previous studies.

For future research, it is recommended that the design of the fuzzy expert system for evaluating and proposing green IT strategies be done using artificial neural networks, which have more advantages than fuzzy expert systems. The study's indices should also be reviewed for reconsideration in Iran or other countries, as laws, regulations, frameworks, and requirements for implementing information technology may differ by country. Designing online questionnaires to make it easier for people to participate in the study is also recommended.

Regarding practical suggestions, the system designed in this study can be used in all industries involved in green products and information technology. The system can also be used in various organizations and industries, and the results can be analyzed to determine the system's strengths and weaknesses and which industry it can perform more successfully in. The system can also evaluate organizations' current conditions and readiness for green IT and make strategic decisions accordingly.

Disclosure statement

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