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Green Computing Innovation Index Measurement Using Fuzzy Inference System for Young Inventors

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ABSTRACT

Green Computing Innovation (GCI) aims to address the negative effects of traditional computing on the environment and promote sustainable practices in computing. Subsequently, the Green Computing Innovation Index (GCII) was used to measure young inventors' inventiveness to evaluate from green computing perspectives. Nonetheless, one of the most significant challenges evaluators face in the measurement process includes uncertainty and imprecise data in measuring the young inventors' green computing innovation. Thus, this paper measures the Green Computing Innovation Index (GCII) with a novel approach utilizing Fuzzy Inference System (FIS) with the Mamdani method. The study measures the top 10 young inventors' innovations from the Faculty of Computing and Meta-Technology, UPSI. Fuzzy Inference System will assist in providing improved decision-making solutions for evaluators to prevent any uncertainty and subjectivity during the evaluation process. The development of FIS is based on four key innovation elements. It uses a triangular membership function with Centroid, Middle of Maximum (MOM), Smallest of Maximum (SOM), Bisector and Largest of Maximum (LOM) methods for defuzzification. The centroid defuzzification method is observed to perform better than other defuzzification methods. It is due to the fact that the adopted defuzzification approach is equally sensitive to all key innovation criteria inputs and can truly represent the minor change in the values of any parameters across all products. The centroid method was found to be the most efficient for decision-making, providing precise results with the ability to detect discrepancies as small as 0.001. Thus, the centroid method can improve decision-making efficiency, leading to fairness in selecting the best green computing innovation product. Ultimately, GCII rating contribute mainly on encouraging young inventors to innovate and promote sustainable practices in innovations.

Keywords:
Innovation; green computing; fuzzy inference systems; young inventors

1. Introduction

Green computing is the study and practice of efficiently designing, using, disposing, and manufacturing Information Technology (IT) equipment with little or no negative environmental impact [1, 2]. One of the most significant issues the global IT industry has dealt with in recent years

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is the best way to utilize technology without affecting the environment. Based on [3], it estimates that the carbon emissions of the IT industry account for 2% of global carbon emissions. As a result, several businesses all over the globe have adopted green computing approaches and successfully lowered their carbon footprints to 30–90% [4]. Due to the fact that not all sectors can implement such initiatives, this transformation is still a significant problem for the IT sectors to adopt [5]. Therefore, innovation in green computing, known as Green Computing Innovation (GCI), is essential in solving these environmental problems.

Furthermore, young inventors refer to people (children or adolescents) involved in invention [6]. We focus specifically on young inventors in higher education institutions because they are at the forefront of this GCI, as they develop new and creative ways of innovations to reduce the carbon footprint of IT equipment and processes [7, 8]. This age range is significant as it covers a critical period where young people acquire knowledge and skills that can influence their behavior and decision-making in the future [9, 10]. Furthermore, this age range also includes individuals currently enrolled in higher education institutions, where they can develop and showcase their innovative ideas through various academic activities, such as Final Year Projects (FYP) and innovation competitions.

For instance, The World Youth Report highlighted and recognized a number of young people's socially transformative innovations [11]. Consequently, encouraging youth innovativeness has grown increasingly over the last ten years. In addition, it inspires millions of young people worldwide to participate in scientific fairs funded by the government and industry [12]. Ultimately, these efforts have the potential to significantly contribute to achieving the Sustainable Development Goals (SDGs) and mitigating the negative impacts of climate change.

Moreover, since GCI are multifaceted and dependent on various factors, we come out with a rubric previously developed that will be used as input scores for evaluation. In this research, the GCI focuses on four key innovation elements: collaboration, ideation, implementation, and value creation [13]. These four key innovation elements are associated with three main green computing approaches. The green computing approaches are design, usage, and disposal [14]. However, the challenge of accurately measuring the Green Computing Innovation Index (GCII) based on these factors highlights the need for a fuzzy inference system.

Therefore, we employ fuzzy inference systems that are capable of handling subjective and vague input by measuring GCII as the final score. Furthermore, this method can prevent biases among evaluators, such as different points of view and opinions in rating GCII, as FIS also capable of mimicking human logical sense [15-17]. Thus, FIS is developed in this study to assist in the decision-making process made by evaluators in measuring GCII. Additionally, we compared several defuzzification methods, including the Centroid, Middle of Maximum (MOM), Smallest of Maximum (SOM), Bisector and Largest of Maximum (LOM) methods [18]. These methods are employed to obtain crisp output values from the fuzzy output sets generated by the FIS. By comparing the results obtained from these defuzzification methods, we aim to determine the most suitable method for measuring GCII reliably and accurately.

The objective of this study is to develop a novel approach, the Green Computing Innovation Index (GCII), using the Fuzzy Inference System (FIS) with the Mamdani method, to provide a precise rating system for measuring young inventors' innovations from green computing perspectives. The study aims to address the challenges faced by evaluators in the measurement process, such as uncertainty and imprecise data. Additionally, the GCII rating system allows inference to be performed in a more natural way using linguistic variables rather than numerical values and method handling multiple attributes. The study's ultimate goal is to encourage young inventors to innovate and promote sustainable practices in computing by improving decision-making efficiency and providing fair and precise results.

This paper is structured as follows: Section 2 outlines our research methodology, which utilizes fuzzy inference systems to rate GCII. Section 3 presents our findings and discussion. Finally, in Section 4, we provide our conclusions about this research.

2. Methodology

Fuzzy logic is a set of mathematical principles for representing knowledge based on degrees of membership. Fuzzy logic has more than two values, unlike Boolean logic. It is concerned with membership and truth degrees [19-21]. Fuzzy logic employs a logical value scale ranging from 0 (completely false) to 1 (completely true). The renowned paper "Fuzzy Sets" by Lotfi Zadeh was published in 1965 [22,23]. Zadeh's work on possibility theory was extended into a formal system of mathematical logic, and he introduced a new concept for using natural language terms. Fuzzy logic [22, 23] was called to this new logic for representing and manipulating fuzzy terms.

A fuzzy inference system (FIS) utilizes fuzzy logic to map an input space to an output space. A FIS attempts to formalize human language reasoning using fuzzy logic (by constructing fuzzy IF-THEN rules). The FIS converts a set of numerical variables (i.e., crisp variables) to a set of fuzzy variables. It is accomplished through the execution of a set of logical rules and linguistic variables. The FIS's core rules are organized in the "IF-THEN" format. The input must be fuzzified before applying these rules, and the conversion is calculated using membership functions [24]. Membership functions are mathematical functions that demonstrate where an element meets into a fuzzy set [25]. There are many different types of membership functions like trim, trap me, belief, Gaussmf, Gauss2mf etc., [26] for the development of FIS. Finally, the defuzzification method converts the fuzzified value to a crisp value.

In this study, the Green Computing Innovation Index was calculated using the Mamdani method by following the procedure shown in the flowchart in Figure 1.

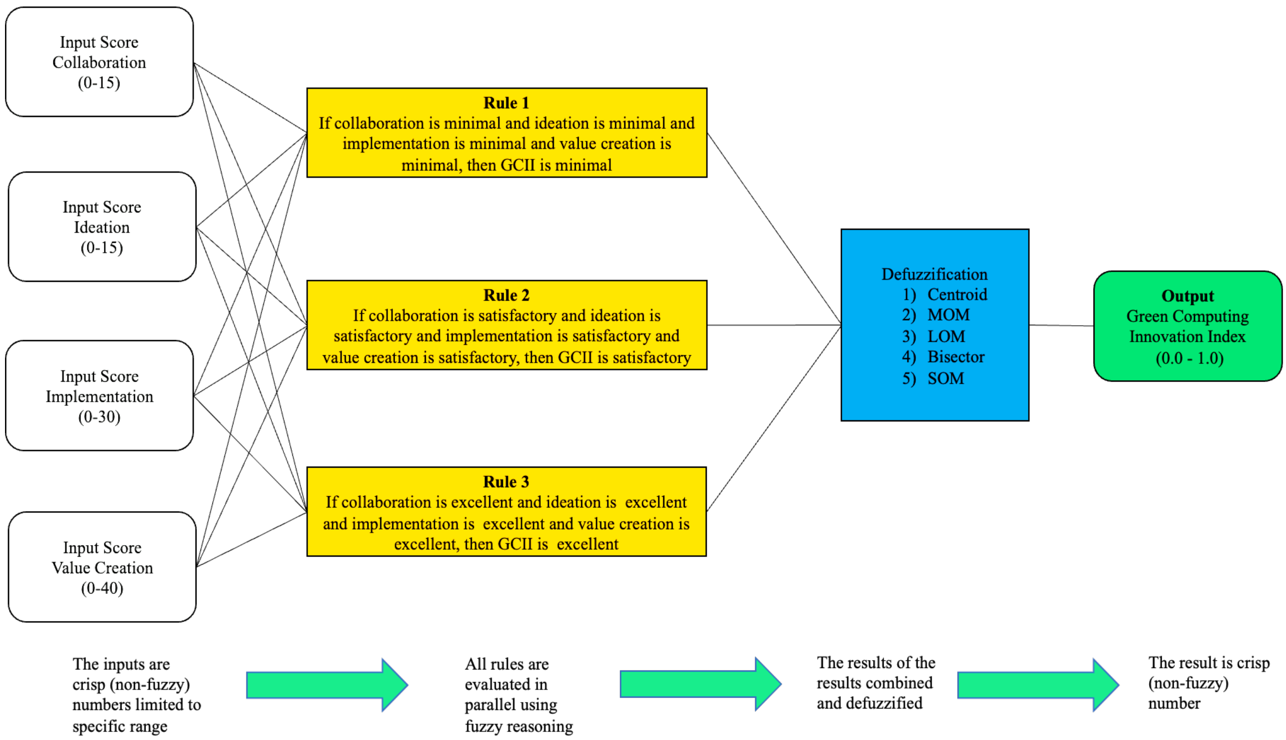

Fig. 1. Process flow diagram of FIS for measuring GCII

2.1 Input Data

This paper uses four key innovation elements incorporated with three GCI variables to find Green Computing Innovation Index. The membership function is adopted from the Green Computing Innovation Rubric, developed previously with the domain experts. The details of all input parameters are as follows:

2.1.1 Collaboration

In the present study, collaboration is examined with three criteria. Each criterion holds the same level of weight of 5%. The first criterion is collaborators are evaluated based on their ability to collaborate internally, nationally, and internationally [27]. Second, the effectiveness of collaborative mediums in facilitating communication and cooperation among team members or external parties was assessed [28]. Finally, problem-solving strategies were evaluated based on their originality, creativity, and effectiveness in identifying and addressing challenges presented by the innovation [29].

2.2.2 Ideation

In this research, ideation is defined as a process for generating unique and fresh ideas that can benefit both the individual and the wider community [30]. The first criterion of ideation is the creation of ideas with a weight of 5%, evaluated based on the ability to identify creative solutions to problems and generate new ideas that meet specific requirements. Next, an ideation design with a weight of 10% was required to design a plan that meets the criteria, constraints, and intent of the problem [31].

2.2.3 Implementation

Implementation innovation elements consist of three criteria with contributing weight of 10% each. First, the potential commercialization was assessed based on market research and stakeholder involvement [32]. The value proposition was evaluated based on feasibility and refinement [33]. Last, the readiness of the innovation for the demonstration was assessed, with the fully developed and tested innovation deemed to have the highest likelihood of success [34].

2.*3.4 Value Creation*

The value creation element consists of economic and social criteria with a weight of 5% each, whereas three main green computing approaches under the criteria of the environment with a weight of 10% each. Value creation's economic aspect involves affordability and innovation's positive impact on economic growth [35]. The social dimension considers the potential of innovation to produce social benefits in targeted communities [36]. The green design principles aim to reduce the environmental impact by eco-designing objects and services. The green usage principles aim to minimize hazardous materials and electricity consumption. In contrast, the green disposal principles aim to recycle e-waste and repurpose existing equipment or employ appropriate disposal methods [37].

2.2 Fuzzification

The data gathered from the GCI Rubric will go through a fuzzification process. Each criterion of key innovation elements as input will be classified and expressed in a linguistic expression, for instance, minimal, satisfactory, and excellent. Then, each linguistic expression will be grouped in the range interval, as presented in Table 1. We adopted the triangular membership function for key innovation elements for this research, as shown in Figure 2. This stage involves matching each key innovation element's score with three interval membership values to determine the GCII tendency for that element.

Table 1
Linguistic expressions and intervals for input criteria

Key Innovation elements	Linguistic expression		
	Minimal	Satisfactory	Excellent
Collaboration	(0, 0, 7.5)	(3.75, 7.5, 11.25)	(7.5, 15, 15)
Ideation	(0, 0, 7.5)	(3.75, 7.5, 11.25)	(7.5, 15, 15)
Implementation	(0, 0, 15)	(7.5, 15, 22.5)	(15, 30, 30)
Value Creation	(0, 0, 20)	(10, 20, 30)	(20, 40, 40)

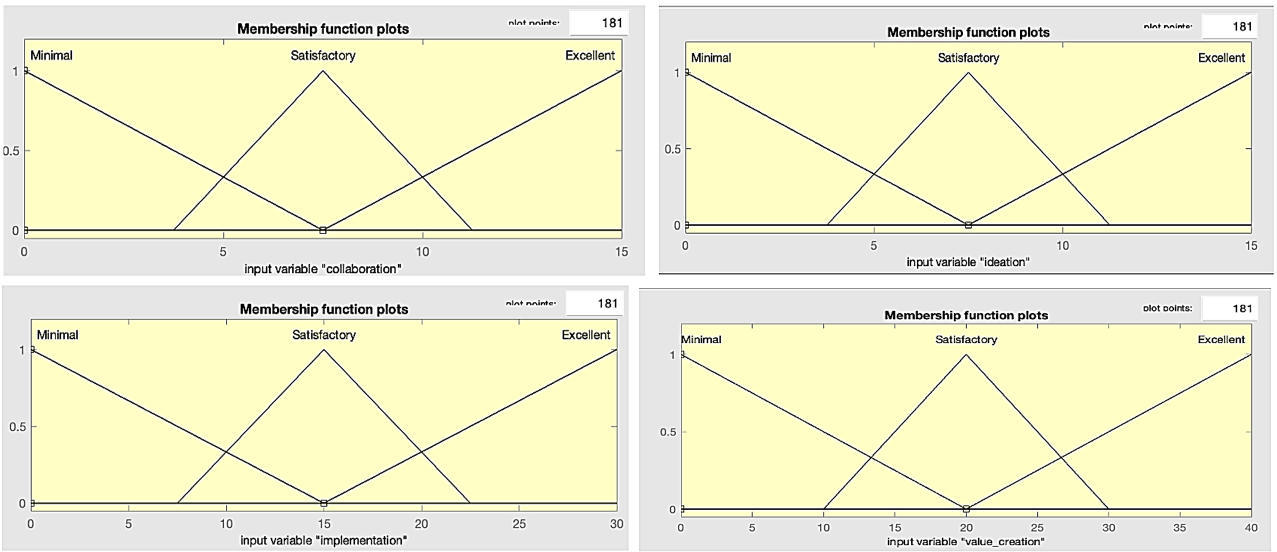

Fig. 2. Membership functions of input variables

2.3 GCII Rules Evaluation

Rules evaluation is the main stage in the FIS method. This stage obtains the GCII membership value based on all its key innovation elements' membership values. If-then rules are used in the inference process for generating output decisions. This rule will determine the study's outcome because it represents decision-making and logical human judgment, usually expressed in linguistic terms. All the key innovation elements were calculated using the union and intersection operation approach to fuzzy sets by the AND logic. The if-then rules used for measuring GCII are shown in Table 2.

At the end of this stage, we will obtain the fuzzified GCII value on each key innovation element. This value is then used to determine the GCII score for each innovation by utilizing the defuzzification method.

Table 2
If-then rules for measuring GCII in FIS

Rule No.	Rules
1	If collaboration is minimal and ideation is minimal, implementation is minimal, and value creation is minimal, then GCII is minimal
2	If collaboration is satisfactory and ideation is satisfactory, implementation is satisfactory, and value creation is satisfactory, then GCII is satisfactory
3	If collaboration is excellent and ideation is excellent, implementation is excellent, and value creation is excellent, then GCII is excellent

2.4 Defuzzification

In the defuzzification stage, the GCII is calculated from the GCI key elements fuzzified value obtained from the previous stage mapped to the triangular membership functions. The GCII range interval and triangular membership function are presented in Figure 3 and Table 3, respectively. From the mapping result, the GCII is then obtained using the five different defuzzification methods, including the Centroid, Middle of Maximum (MOM), Smallest of Maximum (SOM), Bisector and Largest of Maximum (LOM).

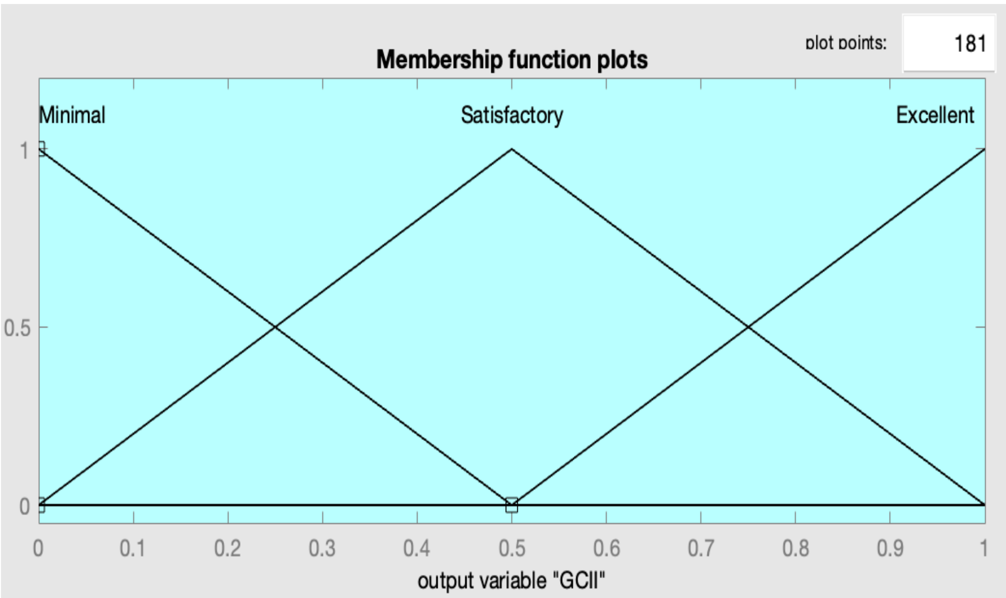

Fig. 3. Membership functions of the output variable (GCII)

Table 3
Linguistic expressions and intervals for output GCII

	Linguistic expression		
	Minimal	Satisfactory	Excellent
Green computing innovation index (GCII)	(0.0, 0.0, 0.5)	(0.1, 0.5, 1.0)	(0.5, 1.0, 1.0)

3. Results

From the results obtained in Table 4, MOM, SOM, and LOM defuzzification methods were found to be less sensitive and precise because they were unable to read the different ranges of data. Therefore, it could be challenging for young inventors who need more accurate and reliable results to change and improve their innovations. As a result, more sensitive and precise defuzzification methods in measuring GCII are required.

Table 4
Linguistic expressions and intervals for output GCII

Key innovation elements input scores					Defuzzification				
Innovation	Collaboration	Ideation	Implementation	Value creation	Centroid	MOM	SOM	Bisector	LOM
1	10	10	20	26.67	0.543	0.835	1	0.54	1
2	10	10	20	26.67	0.543	0.835	1	0.54	1
3	10	10	20	26.67	0.543	0.835	1	0.54	1
4	10	10	16.67	26.67	0.506	0.5	0.83	0.51	0.83
5	10	10	20	26.67	0.543	0.835	1	0.54	1
6	10	10	20	26.67	0.543	0.835	1	0.54	1
7	10	12.5	20	26.67	0.791	0.835	1	0.79	1
8	10	10	20	26.67	0.791	0.835	1	0.79	1
9	10	10	20	26.67	0.543	0.835	1	0.54	1
10	10	10	20	26.67	0.543	0.835	1	0.54	1

Subsequently, the bisectors and centroid methods were more sensitive and precise in detecting differences in the data. The centroid method, in particular, was more precise, with the ability to detect discrepancies up to 0.001. This level of precision can be highly beneficial in accurately evaluating various innovations and producing reliable results. Moreover, the centroid method finds the center of gravity of the data and thus produces more accurate results. This method can also provide a more comprehensive view of the data because it considers all of the values in the dataset, as opposed to the bisector, which only considers the midpoint between the highest and lowest values [38]. Therefore, the centroid is able to produce more precise and accurate GCII compared to other defuzzification methods in this research.

From the centroid point of view, Innovation 7 and 8 achieved the highest score of any product on the Green Computing Innovation Index, which was 0.791. Based on the four criteria, this suggests that Product 7 and Product 8 are the most innovative. However, it should be noted that the scores range from 0.543 to 0.791. This is because all of the products have demonstrated a high level of GCI.

Apart from that, all four key innovation elements contribute equally to defuzzification results. All of the innovations in the study showed evidence of collaboration among individuals or organizations, which may have contributed to the high levels of innovation observed across all five defuzzification methods. Ideation was another vital factor that may have influenced the defuzzification results. The degree of ideation varied across the different innovations in the study, with some demonstrating greater creativity and originality than others. Therefore, it may have affected the scores obtained from the defuzzification process, particularly in the Bisector and Centroid methods which were more sensitive to small differences in scores.

Implementation was also a critical factor in determining the degree of innovation of the GCI. Furthermore, the implementation also influenced the scores obtained from the defuzzification process, particularly in the LOM method, which relied on the maximum score achieved in each element. Finally, value creation, where the innovations are able to demonstrate clear sustainability elements, is highly rated in the study, particularly in the MOM and SOM methods, which were more focused on identifying the maximum score achieved in each element. Overall, it can be inferred from the above findings that the Fuzzy Inference System utilizes Mamdani mimic similar to human reasoning when calculating the GCII by taking into account various factors and weighing their importance in determining the final score.

Moreover, GCII also be used to measure the Faculty of Computing and Meta-Technology's success in promoting innovation in green computing. The high scores obtained by the products indicate that the Faculty has successfully developed innovative solutions to the challenges of green computing. It could also serve as a benchmark for other institutions developing innovative green computing projects.

Therefore, young inventors can use the GCII to evaluate their products' innovative potential in green computing. The GCI Framework and Rubric can serve as a guide for young inventors as they develop their innovations. The obtained scores can then be used to enhance the products and develop more innovative green computing products.

4. Conclusions

The process of qualitative evaluation, which entails innovation in green computing perspectives, is often characterized by subjectivity. It can result in challenges in deciding the index value for GCI, where a range of criteria is involved in the measurement. Based on the results of this study, Mamdani FIS demonstrated its ability to overcome several difficulties faced by the evaluators. Moreover, this approach has resulted in streamlining evaluators' responsibilities, as they are no longer required to undertake the complex and time-consuming tasks associated with conventional methods. Ultimately, FIS explicitly designed to ensure fairness and transparency during the measurement of GCII.

Thus, it is possible to prevent any unfavorable and unethical behaviors on the part of evaluators, such as bias, favoritism, stereotyping, unfairness, and prejudice. The utilization of the Fuzzy Inference System can be valuable for emerging young inventors from the perspectives of GCI, as it offers a systematic and unbiased way of evaluating their innovation. Hence, this transparent approach gives young inventors a comprehensive understanding of the GCII measurement process and encourages them to improve their innovation to achieve a higher GCII score.

Furthermore, the main contribution of this research is the introduction of a novel approach for evaluating GCI, utilizing the Fuzzy Inference System (FIS) with the Mamdani method to measure the GCII. This approach addresses challenges related to uncertainty and imprecise data in the evaluation process. By providing improved decision-making solutions, the FIS based GCII measurement process reduces subjectivity and enhances the accuracy of assessing young inventors' GCI. Additionally, the transparent and unbiased evaluation approach fosters fairness and transparency, encouraging young inventors to strive for higher GCII scores and promoting a culture of sustainable practices.

In future work, further exploration can be conducted to refine the FIS model by incorporating additional criteria and parameters relevant to green computing innovation. This would ensure a more comprehensive and accurate assessment of young inventors' contributions to sustainable computing practices.

Additionally, it would be valuable to assess the long-term impact of the GCII ratings on the continued engagement of young inventors in green computing innovation by expanding the sample size beyond the top 10 innovations. Currently, this research is limited to evaluating the top 10 innovations from the Faculty of Computing and Meta-Technology, UPSI. However, future studies could enhance the generalizability of the findings by including a larger sample size and incorporating innovations from other higher education institutions. By expanding the sample size and including diverse innovations from multiple institutions would provide deeper insights into the long-term influence of GCII ratings on the ongoing innovation efforts of young inventors in green computing.

Overall, the objective of this study, which is to assist in the decision-making process made by evaluators in measuring GCII, is achieved through Mamdani FIS. Therefore, GCII FIS is a promising tool for Young innovators to guide the nation towards a more sustainable approach with the help of this GCII.

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References

[1] Khan, Parvez Alam, Satirenjit Kaur Johl, and Shireenjit K. Johl. "Does adoption of ISO 56002-2019 and green innovation reporting enhance the firm sustainable development goal performance? An emerging paradigm." *Business Strategy and the Environment* 30, no. 7 (2021): 2922-2936. https://doi.org/10.1002/bse.2779

[2] Ali, Imran, Ngoc Dang Khoa Nguyen, and Ahmad Arslan. "Socially Responsible Consumption of Information Technology Equipment: Case Studies from the Australian Banking Sector." In *Dealing with Socially Responsible Consumers: Studies in Marketing*, pp. 509-530. Singapore: Springer Nature Singapore, 2023. https://doi.org/10.1007/978-981-19-4457-4_27

[3] Ahmed, Arwa Ibrahim. "Understanding the factors affecting the adoption of green computing in the Gulf Universities." *International Journal of Advanced Computer Science and Applications* 9, no. 3 (2018): 304-3011. http://dx.doi.org/10.14569/IJACSA.2018.090342

[4] Airehrour, David, Marianne Cherrington, Samaneh Madanian, and Jagjeet Singh. "Reducing ICT carbon footprints through adoption of green computing." In *Proceedings of the IE 1019 International Conference,* p. 257-263. 2019. https://doi.org/10.12948/ie2019.04.17

[5] Kaur, A., and S. Kaur. "Green computing: Emerging issues in IT." *International Journal of Trend in Scientific Research and Development (IJTSRD)* 3, no. 5 (2019): 438-440. https://doi.org/10.13140/RG.2.1.1729.4248

[6] Shavinina, Larisa V. "Preface." *The International Handbook on Innovation*, Elsevier, 2003. https://doi.org/10.1016/B978-008044198-6/50001-2

[7] da Silva, Liziane Araújo, Ana Regina de Aguiar Dutra, and José Baltazar Salgueirinho Osório de Andrade Guerra. "Decarbonization in Higher Education Institutions as a Way to Achieve a Green Campus: A Literature Review." *Sustainability* 15, no. 5 (2023): 4043. https://doi.org/10.3390/su15054043

[8] Ruiz-Mallén, Isabel, and María Heras. "What sustainability? higher education institutions' pathways to reach the agenda 2030 goals." *Sustainability* 12, no. 4 (2020): 1290. https://doi.org/10.3390/su12041290

[9] Hosany, AR Shaheen, Sameer Hosany, and Hongwei He. "Children sustainable behaviour: A review and research agenda." *Journal of Business Research* 147 (2022): 236-257. https://doi.org/10.1016/j.jbusres.2022.04.008

[10] Ziesemer, Florence, Alexandra Hüttel, and Ingo Balderjahn. "Young people as drivers or inhibitors of the sustainability movement: The case of anti-consumption." *Journal of Consumer Policy* 44, no. 3 (2021): 427-453. https://doi.org/10.1007/s10603-021-09489-x

[11] UNDESA, UN. "Department of Economic and Social Affairs (2016)." *Indicators of Sustainable Development: Guidelines and Methodologies. United Nations, New York* (2016).

[12] Kanevsky, Jonathan, Mathieu Crepy, Edward Fitzgerald, Anya Pogharian, Swathi Sadagopan, and Rajesh Aggarwal. "Youth innovation showcase: Achieving high-impact success with novel technologies." *BMJ Stel* 3, no. Suppl 1 (2017): S37-S40. https://doi.org/10.1136/bmjstel-2016-000176

[13] Siraphatthada, Yananda, Walailuck Witkittiluck, Santi Iamvuthipreecha, and Aroonsri Rattanatanyaporn. "Effects of innovation management on green supply chain management performance within the herbal city: Mediating by green practices." *Rigeo* 11, no. 8 (2021). http://dx.doi.org/10.1080/00207543.2011.571937

[14] Franca, Reinaldo Padilha, Yuzo Iano, Ana Carolina Borges Monteiro, and Rangel Arthur. "Better transmission of information focused on green computing through data transmission channels in cloud environments with rayleigh fading." *Green computing in smart cities: Simulation and techniques* (2021): 71-93. https://doi.org/10.1007/978-3-030-48141-4_5

[15] El-Osery, A., and Mohammad Jamshidi. "Analog and digital image enhancement using fuzzy expert systems." *Soft Computing* 7, no. 2 (2002): 97-106. https://doi.org/10.1007/s00500-002-0177-7

[16] Xiang, Shangjia, Yaqiong Lv, Yifan Li, and Lu Qian. "Reliability analysis of failure-dependent system based on bayesian network and fuzzy inference model." *Electronics* 12, no. 4 (2023): 1026. https://doi.org/10.3390/electronics12041026
[17] Sharma, Rashmi Priya, Ramesh Dharavath, and Damodar R. Edla. "IoFT-FIS: Internet of farm things based prediction for crop pest infestation using optimized fuzzy inference system." *Internet of Things* 21 (2023): 100658. https://doi.org/10.1016/j.iot.2022.100658
[18] Koçak, Sinan, Edit Tóth-Laufer, and László Pokorádi. "Fuzzy failure modes and effects analysis with different defuzzification methods–A case study for bearing manufacturing process." In *2019 IEEE 17th International Symposium on Intelligent Systems and Informatics (SISY)*, p. 103-108. IEEE, 2019. https://doi.org/10.1109/sisy47553.2019.9111602
[19] Zadeh, Lotfi Asker. "Probability measures of fuzzy events." *Journal of mathematical analysis and applications* 23, no. 2 (1968): 421-427. https://doi.org/10.1016/0022-247x(68)90078-4
[20] Ibrahim, Oladimeji, Mutiu Shola Bakare, Temitope Ibrahim Amosa, Abdulrahman Okino Otuoze, Waheed Olaide Owonikoko, Esraa Mousa Ali, Lambe Mutalub Adesina, and Olalekan Ogunbiyi. "Development of fuzzy logic-based demand-side energy management system for hybrid energy sources." *Energy Conversion and Management: X* 18 (2023): 100354. https://doi.org/10.1016/j.ecmx.2023.100354
[21] Gundurouthula, Srikanth, M. Gopal Naik, and Togiti Dhilip. "Construction delay assessment using compound index and fuzzy optimization technique: a case study of hyderabad construction industry." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 34, no. 2 (2023): 30-49. https://doi.org/10.37934/araset.34.2.3049
[22] Zadeh, Lotfi A. "Fuzzy sets." *Information and control* 8, no. 3 (1965): 338-353. https://doi.org/10.1016/s0019-9958(65)90241-x
[23] Zulkefli, Nor Atirah Izzah, Yeak Su Hoe, and Nor Afifah Hanim Zulkefli. "Fuzzy predator-prey systems by extended runge-kutta method with polynomial interpolation technique." *Semarak International Journal of Machine Learning* 1, no. 1 (2024): 11-19. https://doi.org/10.37934/sijml.1.1.1119
[24] Abidin, Siti Aisyah Zainal, and Nur Suhailayani Suhaimi. "Decision Support System for Diagnosing Mobile Phone Failure using Rule-Based Technique." *Journal of Advanced Research in Computing and Applications* 17, no. 1 (2019): 14-19.
[25] Akhoondzadeh, Mehdi, and Dedalo Marchetti. "Developing a fuzzy inference system based on multi-sensor data to predict powerful earthquake parameters." *remote sensing* 14, no. 13 (2022): 3203. https://doi.org/10.3390/rs14133203
[26] Patel, Monal, and Falguni Parekh. "Forecasting of flood flow of panam river basin using adaptive neuro-fuzzy inference system (ANFIS) and ANN with comparative study." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 2 (2023): 346-359. https://doi.org/10.37934/araset.32.2.346359
[27] Tasopoulou, Konstantina, and George Tsiotras. "Benchmarking towards excellence in higher education." *Benchmarking: An International Journal* 24, no. 3 (2017): 617-634. https://doi.org/10.1108/bij-03-2016-0036
[28] Huang, Yao, Qian Shi, Feniosky Pena-Mora, Yujie Lu, and Charles Shen. "Exploring the impact of information and communication technology on team social capital and construction project performance." *Journal of Management in Engineering* 36, no. 5 (2020): 04020056. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000804
[29] Graesser, Arthur C., Stephen M. Fiore, Samuel Greiff, Jessica Andrews-Todd, Peter W. Foltz, and Friedrich W. Hesse. "Advancing the science of collaborative problem solving." *Psychological science in the public interest* 19, no. 2 (2018): 59-92. https://doi.org/10.1177/1529100618808244
[30] Dkhil, Abdellatif, Houcine Dammak, Marouane Mouatassim, and Mickael Gardoni. "A new approach to ideation based on linkography combined with graph theory." *International Journal on Interactive Design and Manufacturing (IJIDeM)* 16, no. 2 (2022): 627-642. https://doi.org/10.1007/s12008-022-00846-9
[31] Purzer, Şenay, Jenny Quintana-Cifuentes, and Muhsin Menekse. "The honeycomb of engineering framework: Philosophy of engineering guiding precollege engineering education." *Journal of Engineering Education* 111, no. 1 (2022): 19-39. https://doi.org/10.1002/jee.20441
[32] Nygaard, Kenneth, Morten Graversgaard, Tommy Dalgaard, Brian H. Jacobsen, and Stefan Schaper. "The role of stakeholder engagement in developing new technologies and innovation for nitrogen reduction in waters: A longitudinal study." *Water* 13, no. 22 (2021): 3313. https://doi.org/10.3390/w13223313
[33] Sehnem, Simone, Adriane A. Farias SL de Queiroz, Susana Carla Farias Pereira, Gabriel dos Santos Correia, and Edson Kuzma. "Circular economy and innovation: A look from the perspective of organizational capabilities." *Business Strategy and the Environment* 31, no. 1 (2022): 236-250. https://doi.org/10.1002/bse.2884
[34] Ryabov, Victor, Vladimir Ananishnev, Valentin Fursov, Alexander Tkachenko, Svetlana Osmolovskaya, and Tatiana Frolova. "Modernization of higher vocational education on the example of medical universities: Features of IT

implementation." *World Journal on Educational Technology: Current Issues* 14, no. 1 (2022): 42-55. https://doi.org/10.18844/wjet.v14i1.6227
[35] Howell, Rachel, Cees van Beers, and Neelke Doorn. "Value capture and value creation: The role of information technology in business models for frugal innovations in Africa." *Technological Forecasting and Social Change* 131 (2018): 227-239. https://doi.org/10.1016/j.techfore.2017.09.030
[36] Faludi, Julianna. "How to create social value through digital social innovation? Unlocking the potential of the social value creation of digital start-ups." *Journal of Social Entrepreneurship* 14, no. 1 (2023): 73-90. https://doi.org/10.1080/19420676.2020.1823871
[37] Rathi, Ms Sarita, Shyamalendu Niyogi, and Jasvinder Kaur. "Challenges and issues faced by IT industries to maintain environmental sustainability." *International Journal of Engineering & Technology* 7, no. 4.5 (2018): 759-762. http://dx.doi.org/10.14419/ijet.v7i4.5.25076
[38] Ali, Abdualmtalab, Usama Heneash, Amgad Hussein, and Mohamed Eskebi. "Predicting pavement condition index using fuzzy logic technique." *Infrastructures* 7, no. 7 (2022): 91. https://doi.org/10.3390/infrastructures7070091