GREEN COMPUTING INNOVATION INDEX MEASUREMENT USING FUZZY INFERENCE SYSTEM FOR YOUNG INVENTORS

THINESSWARAN A/L MUNIANDY

UNIVERSITI PENDIDIKAN SULTAN IDRIS

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ABSTRACT

The objective of this research is to develop a decision support system, the Green Computing Innovation (GCI) Index, using a Fuzzy Inference System to measure green computing innovativeness among young inventors. The fuzzy-based model, established for rating and herein referred to as the GCI Index, is applied to assess ten products. Thus, 13 criteria of the GCI framework can serve as a useful guideline for evaluating and fostering innovation among young inventors. The elements encompass four key innovation elements: collaboration, ideation, implementation, and value creation, as well as three green computing approaches: green design, green usage, and green disposal for young inventors. This research methodology involves four phases. First, Document Analysis led to the identification of 13 main criteria within the GCI. Following this, a Validation and Framework Development phase was conducted where the criteria were subjected to scrutiny by three experts. Through the Item Content Validity Index (I-CVI) and Scale Content Validity Index (S-CVI) methods, a perfect validation score of 1.0 lead to the acceptance of all criteria for rubric development. Subsequently, the GCI Rubric went through validation by an external expert. The final phase, Testing and Analysis, involved the application of the fully validated rubric to the evaluation of ten products utilizing the Fuzzy Inference System. In this research, the Centroid defuzzification method is observed to perform better than the Mean of Maximum, Min of Maximum, Max of Maximum, and Bisector defuzzification methods. This is because the Centroid defuzzification method, equally sensitive to all GCI criteria inputs and capable of detecting discrepancies as small as 0.001, can improve decision-making efficiency and ensure fairness in selecting the best GCI product. Thus, the Centroid defuzzification method can improve decision-making efficiency, ensuring fairness in selecting the best GCI product. The implication of this research is that the GCI Index rating mainly encourages young inventors to innovate and promote sustainable innovation practices.

PENGUKURAN INDEX PENGKOMPUTERAN HIJAU DENGAN MENGGUNAKAN SISTEM 'FUZZY INFERENCE' BAGI PENCIPTA MUDA

ABSTRAK

Objektif penyelidikan ini adalah untuk membangunkan sistem sokongan keputusan, Indeks Inovasi Pengkomputeran Hijau (GCI), menggunakan Sistem Fuzzy Inference untuk mengukur inovasi pengkomputeran hijau dalam kalangan pencipta muda. Model berasaskan fuzzy, yang dibangunkan untuk penarafan yang dirujuk sebagai Indeks GCI, digunakan untuk menilai sepuluh produk. Oleh itu, 13 kriteria rangka kerja GCI berfungsi sebagai garis panduan yang berguna untuk menilai dan memupuk inovasi dalam kalangan pencipta muda. Ia merangkumi empat elemen inovasi utama: kerjasama, idea, pelaksanaan dan penciptaan nilai, serta tiga pendekatan pengkomputeran hijau iaitu reka bentuk hijau, penggunaan hijau dan pelupusan hijau untuk pencipta muda. Metodologi kajian ini melibatkan empat fasa. Pertama, Analisis Dokumen yang membawa kepada pengenalpastian 13 kriteria utama dalam GCI. Selepas itu, fasa Pengesahan dan Pembangunan Kerangka dilaksanakan di mana kriteria-kriteria tersebut dianalisis oleh tiga orang pakar. Melalui kaedah Indeks Kesahan Kandungan Item (I-CVI) dan Indeks Kesahan Kandungan Skala (S-CVI), skor pengesahan sempurna 1.0 menyebabkan penerimaan semua kriteria untuk pembangunan rubrik. Berikutnya, Rubrik GCI telah melalui pengesahan oleh pakar luar. Dalam fasa akhir, iaitu Ujian dan Analisis, rubrik yang telah disahkan sepenuhnya digunakan dalam penilaian sepuluh produk dengan menggunakan Sistem Fuzzy Inference. Dalam kajian ini, kaedah defuzzifikasi Sentroid dianggap paling sesuai untuk mengukur Indeks GCI berbanding kaedah Mean of Maximum, Min of Maximum, Max of Maximum, dan Bisector. Ini kerana kaedah defuzzifikasi Sentroid, yang sama sensitif terhadap semua input kriteria GCI dan mampu mengesan perbezaan sekecil 0.001, dapat meningkatkan kecekapan membuat keputusan dan memastikan keadilan dalam memilih produk GCI terbaik. Implikasi kajian ini, penilaian Indeks GCI menggalakkan pencipta muda untuk menghasilkan dan mempromosikan inovasi yang mampan.

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CVI	Content Validity Index
FIS	Fuzzy Inference System
GCI	Green Computing Innovation
GCII	Green Computing Innovation Index
I-CVI	Item Level Content Validity Index
LoM	Max of Maximum
MoM	Mean of Maximum
S-CVI	Scale Level Content Validity Index
SoM	Min of Maximum

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In September 2021, Malaysia secured third position in the Global Innovation Index 2021 among other upper-middle income economy countries (Jewell, 2021). This indicated that the performance of Malaysia in the Global Innovation Index (GII) underscores the country's emphasis on innovation as a crucial catalyst for economic growth and development. This high ranking of Malaysia can be attributed to multiple factors, such as human capital development, demonstrated by the calibre of STEM graduates and the notable representation of international brands and universities. Furthermore, the nation has proactively implemented strategies and plans to foster innovation, including establishing innovation centres, offering inducements for enterprises to allocate resources towards research and development and executing schemes to promote entrepreneurship among citizens (Hanifah et al., 2019).

The Intellectual Property Corporation of Malaysia (MyIPO, 2020) recorded 7,015 patents all over the country, which serves as a noteworthy metric of the country's innovation performance. This depicts how our nation progressively promotes intellectual property and fostering growth propelled by innovation. In addition, the Malaysian government also does not restrict patent activity solely to conventional industries such as manufacturing and technology but rather encompasses a diverse range of fields, including biotechnology, green technology, and healthcare, for the sustainable future of our nation (T. H. Oh et al., 2018; Raihan et al., 2023; Rasiah, 2019).

Innovation is the pivotal determinant of economic progress and global competitiveness. By utilising its innovative capabilities, a nation can sustain its capacity to secure more foreign investment, foster entrepreneurial activity and achieve a high rate of employment opportunities. Hence, a country must focus on innovation and allocate resources towards research and development (R&D) to ensure prosperity (Saqib et al., 2024). Our country has proactively arranged diverse competitions, hackathons, and challenges to foster innovation to motivate students, graduates, and researchers to create innovative solutions to tackle societal issues (Schulten et al., 2022). The competitions serve as a medium for contestants to exhibit their inventiveness, analytical skills, and ability to resolve complex problems. Moreover, engaging in such contests can facilitate cultivating an entrepreneurial mindset and promote entrepreneurship skills, expanding our domestic economy (Garcia-Castanedo et al., 2024).

The Malaysia Science and Foresight Initiative 2050 was initiated in 2017 (Envisioning Malaysia 2050: A Foresight Narrative, 2017) to align with Malaysia's objective of attaining a position among the top 20 developed nations globally. This aims to foster scientific inquiry and advancement across diverse domains such as biotechnology, nanotechnology, and artificial intelligence to propel economic progress and augment the welfare of society. The initiative aims to position Malaysia as a centre for experts in drawing skilled individuals, financial resources, and global partnerships. By focusing on innovation and research, Malaysia can contribute more valuable innovations towards a better future for humankind (Sukri et al., 2023). Hence, assessing innovations related to green computing approaches will encourage and promote more sustainable innovation.

1.2 Research Background

The significance of innovation as a fundamental catalyst for economic growth and resilience has been widely known. The ability to generate novel products and services, parallel to the enhancement of pre-existing ones, increased its competitiveness and productivity. The significance of incorporating environmental impact awareness into innovative products and processes has been given extra focus due to the recent environmental impacts like climate change, global warming and pollution (Bradu et al., 2022). Similarly, green computing brings a more excellent foundation of sustainable development to reduce the ecological footprint of IT equipment (Wang et al., 2021).

The Ministry of Science, Technology, and Innovation carried out a National Survey of Innovation in 2018 (Yusr et al., 2022), known as a benchmarking survey of our country the innovation level, which evaluated innovation in the aspects of technical specifications, components and materials, integrated software and functional characteristics such as user-friendliness. Nonetheless, the assessment considered innovations from green computing perspectives. This clearly showed that there has been increasing recognition of imperative sustainable innovations through competitions and exhibitions. However, the existing assessment standards do not consider green computing perspectives when accessing such innovations.

The field of green computing has given a greater focus on environmental science to promote sustainable practices. For example, in power and energy management, utilising hardware and software devices that are environmentally friendly and increasing product lifespan using recyclable materials (Almalki et al., 2023). Therefore, assessing innovation through the lens of green computing helps to give a prominent solution for prolonging environmental issues.

Apart from that, there are several benefits of implementing green computing, such as lower carbon dioxide emissions, financial gains through lower energy consumption and resource utilisation, increased recycling and reutilization, prevented the release of perilous substances and encouragement of appropriate product disposal without causing safe and not harming the environment (K. Du et al., 2019).

Green computing is a significant aspect of environmental awareness in higher education that is particularly relevant to young inventors. It refers to designing, using, disposing and manufacturing environmentally friendly electronic devices, focusing on reducing energy consumption, minimising electronic waste, and promoting sustainability within the Information Technology (IT) industry (Malik et al., 2019).

Moreover, in the context of researching young inventors, it is essential to understand the distinction between an inventor and an innovator. While both play crucial roles in the development and application of new ideas, they differ in their approaches and contributions to the innovation process. Inventors are individuals who are primarily focused on creating new products, processes or technologies through their expertise and knowledge base (N. Zhang et al., 2023). They often exploit highly impactful knowledge areas and take the initiative quickly to generate patents, showcasing their strong educational background and innovative capabilities (S. Zhu et al., 2022). This aligns with the phenomenon that most inventors pursue outcomes for generating patents, emphasizing their commitment to tangible and practical outcomes (H. Yang et al., 2023).

Whereas, innovators are individuals who are more focused on the implementation and commercialization of new ideas, often leveraging existing inventions to create value in the market (D'Souza et al., 2024). They are instrumental in the commercialization of technology and the successful integration of inventions into the market (Sergeevna, 2020). Therefore, in the context of young inventors, it is crucial to justify the focus on inventors rather than innovators in research. This is because understanding the unique knowledge base, educational background, and initiative-taking behaviour of young inventors can provide valuable insights into their contributions to the innovation process, particularly in terms of patent generation and technological advancements.

The study of young inventors who participate in international youth invention exhibitions can offer valuable insights into their hands-on attitude, epistemic curiosity, and interests in science, technology, engineering, and mathematics (STEM) careers (Cui et al., 2022). This highlights the significance of focusing on young inventors, as their participation in such exhibitions reflects their early engagement and interest in innovation and invention, which can have long-term implications for their career trajectories and contributions to the innovation ecosystem (Cui et al., 2022).

Additionally, the consideration of inventor turnover, collaboration patterns, and individual inventor characteristics in recombinant innovation further emphasizes the importance of studying young inventors and their influence on innovation outcomes within firms (Khanna & Guler, 2022). As younger inventors may still be uncertain about their productivity and have their careers ahead of them, understanding their collaboration patterns and the consequences of their characteristics can provide valuable insights into their potential impact on innovation outcomes (Nagler & Sorg, 2019).

In conclusion, the focus on young inventors in research is justified due to their unique knowledge base, educational background, hands-on making attitude potential long-term contributions to the innovation ecosystem. By studying young inventors, researchers can gain valuable insights into their early engagement in invention and innovation, their collaboration patterns, and their potential influence on innovation outcomes within firms.

1.3 Problem Statement

The significance of green computing has recently increased due to technology's adverse environmental effects (Nwankwo et al., 2020). The process entails designing, using, disposing and manufacturing environmentally sustainable computing appliances. Although the implementation of green computing is increasingly practised, the measuring rate of green computing by assessing innovation still needs to be more adequately defined (Dalvi-Esfahani et al., 2020). Hence, the standardised evaluation criteria are needed to rate environmentally sustainable computing innovations.

Furthermore, few eco-label programs support green computing for a standard evaluation. One of the prominent eco-labels that is widely recognised in the information technology sector is the Energy Star eco-label. Research has shown that consumers' knowledge of eco-labels, such as Energy Star, plays a crucial role in enhancing trust and purchase intention for energy-efficient products (Waris & Ahmed, 2020). Moreover, eco-certifications like Energy Star have been associated with improved financial performance and lower operating expenses in certain industries, indicating the positive impact of such eco-labelling programs (Izon & Islip, 2021).

The influence of information provision through eco-labelling on consumer choices has also been a subject of study, highlighting the significance of eco-labels in shaping consumer behaviour and preferences (Cenci, Scarazzato, Munchen, Dartora, Veit, et al., 2022). Furthermore, the Energy Star program has been recognized as a pioneering effort to promote energy-efficient technology and product sales, contributing to the global goal of sustainable development (G. Zhang et al., 2021). However, it is essential to note that the effectiveness of eco-labelling, including Energy Star, in influencing consumer purchasing intention may vary across different products and markets (Ali & Elshahhawy, 2019).

On the other hand, MyHijau is a government initiative that promotes eco-friendliness in all aspects and emphasises sustainable practices in various industries (Abdul Hadi et al., 2022). Implementing eco practices is part of the broader MyHijau initiative, which aligns with the 12th Malaysia Plan (Hamid et al., 2021). The pressing demand for green, safe and economically sustainable practices has made green approaches a significant concern in the industry (Khaderi et al., 2022).

Both the Energy Star Label and MyHijau are essential in promoting sustainable practices and raising awareness about environmental issues in Malaysia. This helps consumers make informed choices about computer products and encourages sustainable practices in various industries. However, Malaysian customers' awareness of green products is still relatively low, and eco-labelling is recommended to increase customer preferences towards green products in Malaysia (Ghazali et al., 2021).

Furthermore, green competing innovation assessment in higher education institutions is a crucial aspect of promoting sustainability and environmental responsibility. For instance, a study explored the level of use of ICTs in higher educational institutions about awareness and adoption of green computing (Mbewe, 2019). The findings of this study are relevant as they emphasize the importance of incorporating green computing practices within educational institutions.

In addition, the research by Vakaliuk et al. (2020) discussed green IT as a tool for designing a cloud-oriented sustainable learning environment in higher education institutions. This study is relevant as it emphasizes the potential of green IT in creating sustainable learning environments within educational institutions. However, there is a lack of rubrics that are tailored specifically to incorporate green computing innovation evaluation. Thus, the need for a green computing innovation rubric in higher education institutions is justified by the growing emphasis on environmental responsibility and sustainability in educational settings (Jnr et al., 2019). A rubric tailored specifically for assessing green computing innovation would provide a standardized framework for evaluating the integration of sustainable practices. This would enable institutions to systematically assess their progress in adopting green computing practices and identify areas for improvement.

Therefore, the assessment of green computing innovation in higher education institutions is essential for promoting sustainability and environmental responsibility. The development of a green computing innovation rubric is justified by the need to standardize the assessment process and facilitate the integration of sustainable practices within educational institutions (Rajaram, 2023). In this research, we propose a framework for GCI, which consists of four key innovation elements: collaboration, ideation, implementation and value creation, to fill the existing gap. Furthermore, the framework integrates three green computing approaches: green design, usage, and disposal. The green computing innovation index is evaluated using specific criteria, employing a Mamdani-type FIS.

1.4 Research Questions

The research work aims to address three pivotal research questions that seek to fill the existing gaps in our understanding of the topic at hand.

1. What are the innovation criteria for the four key innovation elements from the green computing perspective?
2. What is the Green Computing Innovation Framework?
3. What is the green computing innovation index of an innovation?

1.5 Research Objectives

In contemplation of answering research questions, the following are the research objectives:

1. To identify the criteria of the four key innovation elements: collaboration, ideation, implementation and value creation from the green perspectives through related studies.
2. To develop a green computing innovation framework from the criteria defined.

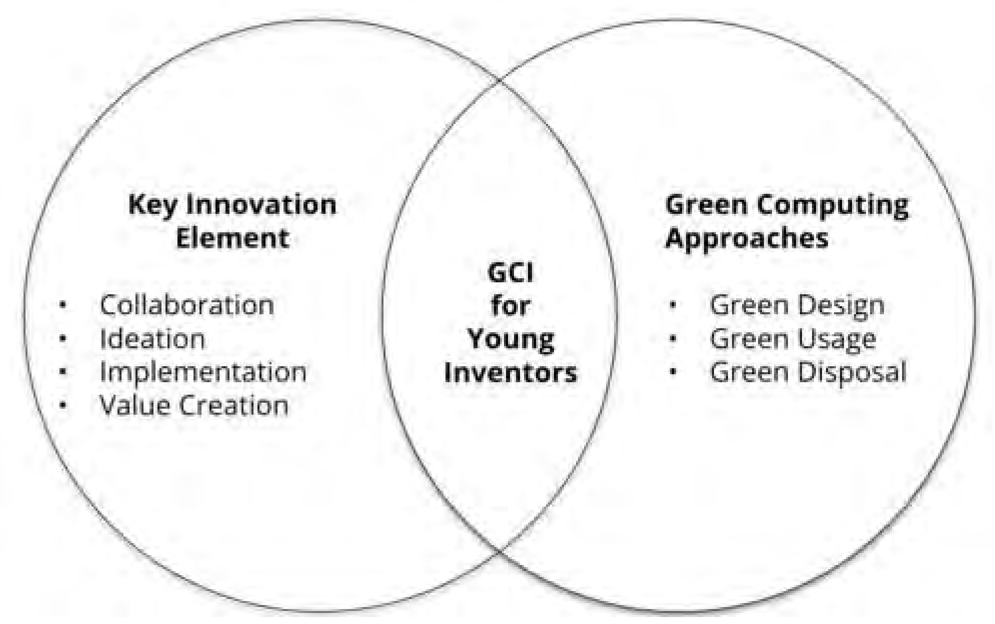
3. To measure the Green Computing Innovation Index (GCII) through a Fuzzy Inference System.

1.6 Research Scope

The primary objective of this research is to measure the index of green computing innovation known as GCII, with a developed GCI framework and rubric. In this study, we focus on green computing innovation which consists of a combination of key innovation elements and green computing approaches as shown in Figure 1.1. The key innovation elements consist of collaboration, ideation, implementation and value creation, whereas green computing approaches consist of green design, green usage and green disposal.

Figure 1.1

GCI Research Scope Diagram



The objective of this study is to rate young inventors' innovations. Therefore, in this research, undergraduate students developed the top ten innovative products in their Final Year Project (FYP) from the Faculty of Computing and Meta-Technology. The products have been selected based on their potential to significantly contribute to the field innovation as evaluated by the Jury previously. In the context of this research, the GCI framework and rubric serve as instrumental tools in achieving research outcomes that directly address the second and third objectives of our study. The first outcome pertains to the development of a green computing innovation framework, which is constructed based on predefined criteria. The second outcome involves the measurement of a degree, referred to as the Green Computing Innovation Index (GCII). This index quantifies the extent to which the components of collaboration, ideation, implementation and value creation align with the green computing approaches of design, usage, and disposal as calculated through a Fuzzy Inference System.

The framework created to promote green computing approaches among young inventors includes an assessment of the effectiveness of collaboration, ideation, implementation and value creation. The collaboration depends on the extent of collective efforts by students, professionals or people in creating innovative products (Muukkonen et al., 2022). Ideation is based on integrating novel and distinctive concepts related to green computing into products (Dulaimi, 2022). The implementation assessment depends on developing and implementing initiatives to drive progress (Onea, 2020). Value creation is creating values where the products ensure bring benefits to the field of green computing (Gomez-García et al., 2022).

The framework can be employed to promote and assess green computing by thoroughly studying the four key innovation elements. Facilitating productive collaboration has the potential to encourage innovative thinking, and integrating novel and distinctive concepts can motivate learners to explore the possibilities of sustainable computing (Fernandez et al., 2019). Implementing these concepts and assessing their ability to add value can benefit the wider community and encourage additional progress in this crucial area. The main objective of the proposed framework is to offer a holistic evaluation to promote the adoption of green computing approaches among young inventors.

The GCI framework in this study focuses on three green computing approaches: i) green design, ii) green usage and iii) green disposal. The green design approach will evaluate the degree to which the young inventors have integrated eco-friendly characteristics into their products (Paparoidamis et al., 2019). For example, innovative products like energy-conserving IT equipment of computers, printers, servers and tablets. Green usage is evaluated based on the utilisation of sustainable resources and the minimisation of product waste (Anthony Jnr, 2020). The green utilisation strategy will assess the capacity of the products to encourage environmentally responsible conduct and reduce their environmental footprint. The analysis will evaluate how students have reduced electricity usage and employed eco-friendly practices when using computers and their devices.

Thirdly, the green disposal approach will evaluate the available end-of-life alternatives for the products without harming the environment (Mann et al., 2022). The assessment of students will consider the capability of products in safe disposal, such as recycling electronic waste with minimal or no adverse effects, reusing pre-existing equipment, and properly disposing of unwanted electronic devices.

However, in this study, we exclude green manufacturing as its scope centres for young inventors because most of the young inventors in higher education institutions still have not yet participated in manufacturing operations. The inventors emphasise the advancement of creating innovation once the production of products is in mass. Moreover, the green manufacturing approach is better suited for the manufacturing industry since it involves more complex and numerous numbers of operations of manufacturing.

Apart from that, a qualitative analysis of ten innovation products that have been selected for evaluation. The primary objective of this analysis is to assess the GCI identified in the research scope. The evaluation will rely on predetermined criteria derived from the proposed GCI framework. Since the GCI innovation elements are multifaceted, the Fuzzy Inference System (FIS) was used in the study to decrease the subjective and vague opinions that arise from the jury in evaluating innovation from GCI perspectives. In addition to the previously mentioned outcomes, this research also necessitates the precise quantification of the GCII. This measurement is particularly crucial for young inventors, as it provides an accurate assessment of the greenness of their innovations. Thus, the determination of GCII serves as another significant outcome of this study, complementing the GCI framework and rubric.

The GCII measurement is a rating that can help young inventors evaluate their innovations' effectiveness. This framework combines GCI criteria and provides a comprehensive index that measures the sustainability of their innovations. The Mamdani fuzzy inference system is utilised in this research to infer the Green Computing Innovation Index output variable based on the green computing innovation criteria input variables.

The Mamdani-type fuzzy inference system is used in this research to calculate GCII. Mamdani-type FIS is a rule-based system that uses fuzzy set theory to handle nonlinear mappings of input spaces to output states, enabling effective decision-making in real-world problems (Varshney & Torra, 2023). It uses linguistic rules based on prior knowledge to generate responses to various stimuli (R. P. Sharma et al., 2023). The FIS utilises IF-THEN rules to infer output variables from input a. The FIS operates on an input space V = V1, V2...VnRn and using fuzzy 'IF-THEN' rules to the output space by mapping in fuzzy set-in input space VRn to fuzzy sets based on the fuzzy operations principle (El Jaouhari et al., 2023).

The fuzzy 'IF-THEN' rules are also made up of experts' knowledge, enabling the incorporation of both qualitative and quantitative data in a parallel manner (Sarihi et al., 2023a). Moreover, the rules in FIS consist of 'IF-THEN' developed based on expert knowledge and can be measured based on mixed qualitative and quantitative methods (Mohamed et al., 2022). The fuzzifier maps crisp scores in the input space to fuzzy sets, while the fuzzified maps fuzzy sets in the output space to crisp scores (Wozniak & Kwolek, 2021). By doing this, the Mamdani FIS can effectively handle the nonlinear mapping between input and output spaces, making it an ideal tool for measuring young inventors' innovation sustainability rating known as GCII.

The Mamdani fuzzy inference system is a powerful tool that can assist young inventors in evaluating the sustainability of their innovations. The GCII measurement can provide a comprehensive index incorporating various metrics to measure sustainability from green computing perspectives. The fuzzy IF-THEN rules allow for the incorporation of experts' knowledge, enabling the integration of both qualitative and quantitative data in a parallel manner (Sarihi et al., 2023b). Therefore, this FIS can aid in promoting the development of sustainable green computing innovations in universities. The Mamdani Fuzzy Inference System is widely used in various fields to model and make decisions based on fuzzy logic. It consists of several stages and has been applied in different applications.

One instance of applying the Mamdani FIS is selecting recipients for Cash Social Assistance in Kabupaten Belitung Timur, as described in the study. The study used the Mamdani Fuzzy Inference System to determine the eligibility of individuals for social assistance based on fuzzy sets, implication functions, rule composition, and defuzzification (Savitri & Suhaedi, 2022). This application demonstrates how the Mamdani Fuzzy Inference System can be used in decision-making processes to allocate resources effectively.

Another example is using the Mamdani Fuzzy Inference System in breast cancer risk analysis, as discussed in the research. The study utilised the Mamdani model to develop a software system that assesses the level of breast cancer risk (Dewi & Sri Haryati, 2022). By inputting relevant data, such as age, family history, and lifestyle factors, the Mamdani Fuzzy Inference System can estimate the risk level, aiding in early detection and prevention efforts.

The Mamdani Fuzzy Inference System is also used to predict the weather. Damayanti et al. (2022) used the Mamdani Fuzzy Inference System to predict rainfall in the Blora Regency. The study achieved an accuracy rate of 66% in predicting rainfall using this method (Damayanti et al., 2022). This application highlights the potential of the Mamdani Fuzzy Inference System in improving weather forecasting and supporting decision-making in areas prone to rainfall-related risks.

Furthermore, the FIS System has been used in production and manufacturing. For example, the Mamdani method is used to determine the quantity of bag production in a bag factory. By considering factors such as demand and supply, the Mamdani Fuzzy Inference System can optimise production levels and improve efficiency in manufacturing operations (Junika Putra et al., 2022).

The Mamdani FIS is a versatile method applied in various fields, including social assistance selection, breast cancer risk analysis, weather prediction, and production optimisation. Its ability to handle fuzzy logic and make decisions based on imprecise or uncertain data makes it a valuable tool in decision-making processes and system modelling.

In summary, this research study aims to measure innovations based on green computing perspectives. The top ten FYP innovations were selected from the Faculty of Computing and Meta-Technology students. This research focuses on four key innovation elements: collaboration, ideation, implementation and value creation with three green computing approaches: i) green design, ii) green usage and iii) green disposal. Overall, in this research, the outcome could serve as a valuable resource for academic instructors and decision-makers in promoting innovations based on green computing perspectives, especially among young inventors.

1.7 Operational Definition

The operational definition of this thesis is as follows:

1. Key innovation elements - collaboration, ideation, implementation and value creation (Siraphatthada et al., 2021).
2. Green computing approaches - green design, green usage and green disposal (Balusamy & Chilamkurti, 2020).
3. Collaboration - collaboration involves group activities that lead to innovation. Collaboration between students, experts or authorities is expected (Audretsch & Belitski, 2023).
4. Ideation - coming up with unique and fresh ideas. Ideation here refers to the broad area that can be explored in multiple approaches for our communities (Swanzy-Impraim et al., 2023).
5. Implementation - implementation of activities towards ideas to progress and move forward (Bachtold et al., 2023).
6. Value Creation - innovation is highly only possible if products receive the value they deserve (Silva & Zancul, 2023).
7. Green Design - Designs IT services and equipment with less environmental harm and energy efficiency, such as servers, projectors, printers and other IT equipment (Balusamy & Chilamkurti, 2020).

8. Green Usage - Utilisations of non-hazardous materials minimise the electricity usage of computers and IT peripheral devices (J. Zhang & Sun, 2024).
9. Green Disposal - Disposing IT equipment more safely without detriment to the environment. For example, repurposing, recycling and reusing computer peripherals and unwanted electronic equipment (Bharti et al., 2023).
10. Young Inventor - based on Youth Solutions Report (Youth Solutions Report 2020, 2020), young people who act as inventors develop the most innovative works when they are young. Consequently, in this research, young inventors refer to youth, as the United Nations (UN) mentioned, between the ages of 15 and 24.
11. Fuzzy Inference System (FIS) - a vital unit of the fuzzy logic system used for decision-making (Anitha et al., 2023).
12. Green Computing Innovation Framework - consists of 13 green computing innovation criteria.
13. Green Computing Innovation Index (GCII) - index value ranges from 0-1 for measuring innovation based on green computing perspectives.

1.8 Significance of the Study

Integrating GCI in a country's innovation ecosystem can enable the development of environmentally conscious technological advances (W. Fang et al., 2022). Consequently, this impacts the country's overall economic growth and progress. Since, green computing has yet to get great awareness in Malaysia (Raihan, 2023). Therefore, the current study is significant as it assesses the feasibility of innovative approaches to promote environmental sustainability by incorporating green computing approaches through the GCI framework. This study uses a FIS to evaluate ten products to provide a rating known as GCII.

The use and implementation of the GCI framework represent a significant step forward in promoting environmentally sound computing in Malaysia. The framework focuses on collaboration, ideation, implementation and value creation with three green computing approaches: green design, usage and disposal, totalling 13 criteria, to facilitate a comprehensive assessment to promote environmental sustainability. The GCI framework could serve as a reference to policymakers and inventors in Malaysia to develop sustainable technological solutions while addressing the country's carbon emissions problem.

The findings of this study have the potential to contribute to understanding the landscape of green computing innovation in Malaysia. This can facilitate the formulation of effective policies and initiatives by policymakers and researchers to strengthen the inclusion of green computing in the innovation ecosystem. The findings of this research can help identify areas that require further research and development efforts to promote the uptake of green computing in the innovation ecosystem.

This study highlights the potential of the Fuzzy Inference System (FIS) as an evaluation tool for assessing innovation. Consequently, this study has the potential to facilitate further research on the Fuzzy Inference System (FIS) domain for alternative areas of green computing innovation. The GCI framework focuses on collaboration, ideation, implementation and value creation. This framework is a comprehensive approach to innovation that involves all stakeholders within the innovation ecosystem. Therefore, this approach fosters the creation of green computing that meets societal needs while minimising negative environmental impacts.

Leveraging the GCI framework has the potential to strengthen Malaysia's global competitiveness. Integrating green computing approaches into the innovation ecosystem can position Malaysia as a leading innovator in sustainable technologies as global markets increasingly value environmentally sustainable technological solutions (Feroz et al., 2021). This research's findings can also help identify best practices for incorporating green computing principles into the innovation ecosystem. By identifying optimal methods, Malaysia can develop policies and initiatives that more effectively facilitate the seamless integration of green computing principles into the innovation ecosystem.

Apart from the above benefits, including young inventors in the GCII has remarkable implications for the future development of green computing. The GCII ensures the contributions of young people to ensure that future inventors are adequately equipped and supported to address the environmental challenges of today's world, for example, by addressing the climate emergency and the need to develop breakthrough approaches to reduce carbon emissions and mitigate the effects of climate change.

1.9 Conclusion

Green computing is a crucial concept that centres on mitigating the environmental impact of electronic and electrical devices through various practices. These practices encompass green design, manufacture, use, and disposal. The primary objective of sustainable computing is to develop environmentally friendly Information and Communication Technologies (ICT) by reducing carbon emissions and conserving energy usage (Cecillia & Tanamal, 2020).

Green computing originated from the Energy Star program, introduced in 1992 as a labelling initiative for computer products that demonstrated maximum efficiency by consuming minimal energy. Energy Star symbolises energy efficiency, promoting adopting energy-saving computer products (Cecillia & Tanamal, 2020).

Besides minimising energy consumption, sustainable computing also encompasses other aspects of the electronic-environment relationship. This includes employing environmentally friendly manufacturing processes, avoiding hazardous components or chemicals, and reducing the impact of e-waste by using cleaner materials and durable product designs. Responsible use of computer resources, such as powering down devices when not in use and reducing energy consumption during periods of inactivity, is also an integral part of sustainable computing. Moreover, developing more efficient components that require less energy and produce less heat is another aspect of sustainable computing (Cenci, Scarazzato, Munchen, Dartora, Veit Hugo Marceloand Bernardes, et al., 2022).

Research indicates that the implementation of sustainable computing practices can have a positive influence on consumer satisfaction, perceived quality, and trust. For instance, a study on Apple consumers in Surabaya revealed that the environmentally friendly approach fostered through green computing positively affected green satisfaction, perceived quality, and trust (Cecillia & Tanamal, 2020).

In education, sustainable computing can be effectively integrated into the curriculum to raise awareness about sustainability issues and promote the use of green technologies. Practical projects involving portable wireless sensor networks have been found to increase students' awareness of sustainability issues and enhance their understanding of the sustainable applications of computer technologies (Grebennikova et al., 2021).

To sum up, sustainable computing is a multi-faceted concept involving various practices to mitigate the environmental impact of electronic and electrical devices. These practices encompass energy-efficient computing, responsible use of computer resources, environmentally friendly manufacturing processes, and e-waste reduction (S. Sharma & Dutt, 2024). Implementing sustainable computing practices can lead to environmental benefits, increased consumer satisfaction, and the promotion of environmental sustainability within the ICT industry (Pazienza et al., 2024).

Green computing is essential today, offering numerous benefits for organisations, individuals, and the environment. Sustainable information systems, a key component of sustainable computing, present opportunities for organisations to enhance productivity, reduce costs, and increase profitability (Grebennikova et al., 2021). Cloud computing, for instance, enables businesses to migrate applications to agile cloud environments, streamlining processes with minimal expenses and management efforts (Paton-Romero et al., 2019).

Within software development, sustainable technology minimises the adverse impacts on the economy, society, human beings, and the environment resulting from software deployment and usage (Saputri & Lee, 2021). By aligning with sustainable development principles, this approach contributes to the broader sustainability objectives of organisations and society, reducing their environmental footprint and promoting a more sustainable future (Malik et al., 2019).

Green computing practices, encompassed by sustainable computing, have garnered significant attention, focusing on minimising the environmental impact of IT operations and infrastructure (Paul et al., 2023). Organisations can achieve social, economic, and environmental benefits through these practices (Bradu et al., 2022). Energy-efficient computing technologies, for instance, reduce energy consumption and carbon emissions, leading to cost savings and a smaller ecological footprint (Paton-Romero et al., 2019).

According to the September 2021 edition of the Global Innovation Index (GII), Malaysia has ranked third among 34 middle-income economies (Jewell, 2021). As per the report, Malaysia sustains this position due to the creation of an innovation hub, human capital development, and incentives for companies. Allocate resources to research, development, and implementation of programmes to support entrepreneurial efforts.

In 2017, the Malaysia Science and Foresight Initiative 2050 (Envisioning Malaysia 2050: A Foresight Narrative, 2017) was launched, aligned with Malaysia's goal to rank among the world's top 20 industrialised nations. It aims to promote scientific exploration and advancement in various fields, including biotechnology, nanotechnology and artificial intelligence, to drive economic growth and improve societal well-being. Green computing is an essential aspect of environmental science that aims to find cost-effective solutions for conserving natural resources and the ecosystem (Nwankwo et al., 2020). Incorporating the principles of green computing innovations into Malaysia's innovation policies and initiatives focuses on young inventors aged between 15 to 24 years old. According to the United Nations (UN) definition (Youth Solutions Report 2020, 2020), individuals within this age range are considered youth. This age bracket is of particular importance as it encompasses a crucial developmental period where young people are actively acquiring knowledge and skills that can profoundly influence their behaviours and decision-making in the future (Statistical Yearbook 2021 Edition, 2021).

The significance of studying young inventors within this age range lies in their potential to drive innovation and contribute to sustainable computing practices. By studying the innovations and achievements of these young inventors, we can gain valuable insights into their unique perspectives and ideas for addressing environmental sustainability challenges. By empowering and engaging young inventors in sustainable computing initiatives, we can tap into their creative potential and enthusiasm, encouraging them to take an active role in driving positive change for the environment. Ultimately, nurturing green computing innovation approaches among young inventors can lead to long-term sustainable practices and contribute to a greener and more sustainable future (Hosany et al., 2022).

By concentrating on young inventors aged 15 to 24, this research aims to contribute to sustainable computing and nurture a generation of environmentally aware inventors who can significantly shape a sustainable future. The insights obtained from this study can inform educational institutions, policymakers, and industries on supporting and harnessing young inventors' creative potential towards addressing global environmental challenges and significantly reducing carbon emissions. By emphasising the importance of green computing, Malaysia could be a pioneer in developing sustainable technologies, benefiting the environment and the country's global competitiveness.

The GCI Framework was developed to rate young inventors' innovation to promote environmental sustainability. The innovation framework comprises 13 criteria divided into four key innovation elements: collaboration, ideation, implementation and value creation, and three green computing approaches: green design, usage and disposal. This quantitative study aims to rate the top 10 FYP innovations from young inventors using FIS with an output score known as GCII. The criteria of the GCI framework were identified through document analysis and validated using content validity methodology. GCI criteria were identified through document analysis methodology of academic literature published between 2019 and 2022, and a group of three content experts validated all the criteria.

Then, the GCI framework was developed based on validated criteria. Based on the GCI framework, we developed a rubric with scale scores to measure an index called GCII using FIS. The Fuzzy Inference System (FIS) is used to assess the GCII as it can account for imprecise and uncertain information. Several studies have delved into the innovation rating specifically in the realm of sustainable practices.

Gu (2023) explored how peer influence and market power affect green innovation in Chinese listed firms, highlighting the significance of understanding the dynamics of green innovation behaviour at the enterprise level. Similarly, Shi et al. (2023) found that ESG ratings positively impact corporate green innovation by alleviating financial constraints and enhancing managers' environmental awareness. These studies emphasize the importance of external factors and performance metrics in driving green innovation initiatives within organizations.

S. K. Singh et al. (2020) and L. Fang et al. (2022)focused on the mediating role of green innovation in enhancing environmental performance through factors like green human resource management and green transformational leadership. These studies underscore the interconnectedness of internal organizational practices and their influence on driving green innovation outcomes.

Moreover, research by Zheng et al. (2022) and Rupasinghe et al. (2023) shed light on how green innovation can impact ESG ratings, financial performance, and competitive advantage. Understanding the mechanisms through which green innovation contributes to overall organizational success is crucial for firms aiming to integrate sustainability practices into their core strategies.

Furthermore, studies by H. Wang et al. (2021) and Rupasinghe et al. (2023) highlight the role of technological advancements, such as green information systems and digital transformation, in fostering green innovation within enterprises. These findings underscore the need for organizations to leverage technological tools to drive sustainable innovation practices effectively.

Green computing initiatives encompass a holistic approach that includes green design, green usage, and green disposal practices to minimize the environmental impact of information and communication technologies (ICT). These initiatives aim to reduce e-waste, promote sustainable consumption and production, and enhance energy efficiency. Implementing green practices such as virtualization, cloud computing, and renewable energies in organizations can significantly contribute to offsetting environmental degradation (Butt et al., 2020). Green computing not only focuses on the design and usage of technology but also extends to disposal methods to ensure proper recycling and management of electronic waste (Podder & Samanta, 2021).

The adoption of green technologies, such as green information technology and green products, is influenced by various factors including individual behavioural intentions, environmental awareness, and ethical beliefs. Consumers' attitudes towards environmental awareness and ethics play a crucial role in their intention to use green products, highlighting the importance of promoting environmental consciousness in society (SAMY et al., 2021). Additionally, the perceived benefits of green technologies influence consumers' purchase and usage intentions, indicating a growing interest in environmentally friendly products (Montero Filho, 2021).

In conclusion, this thesis is organized into five main chapters. The first chapter introduces the research topic and presents the research background, research problem, problem statement, research questions, research objectives, research scope, operational definition, significance of study and conclusion of the study. The second chapter provides a comprehensive review of the literature related to the research topic, highlighting the key innovation elements criteria and sub-criteria, green computing, young inventors and Fuzzy Inference System (FIS) case studies. The third chapter describes the four phases of research methodology of this research including document analysis, validation and framework development, rubric development, fuzzy inference system and conclusion of this chapter. The fourth chapter presents the findings of the study, with detailed analysis and interpretation of the data for green computing innovation framework, rubric and index. The fifth and final chapter discusses the key findings and research implications and suggests areas for future research.