ENVIRONMENTAL ENTREPRENEURSHIP SUSTAINABILITY: EXPLORING ARTIFICIAL INTELLIGENCE, KNOWLEDGE AND FRUGAL INNOVATION

Purpose: The purpose of this study is to examine the impact of knowledge source, Artificial Intelligence (AI), and Frugal Innovation (FI) on Green Entrepreneurial Sustainability (GES). The study also explores the mediating role of FI in the relationship between Sources of Knowledge (SoK) and AI on GES, and the moderating influence of personality traits.

Design/methodology/approach: A sample of 314 respondents was used, with a quantitative cross-sectional design and Structural Equation Modeling (SEM) analysis.

Findings: Results indicate that SoK, AI, and FI have a positive impact on GES, with FI acting as a partial mediator. Personality traits, however, do not moderate the relationship between SoK, AI, and FI on GES. These findings suggest that leveraging knowledge resources and AI can enhance sustainability through frugal innovation, especially in resource-constrained environments.

Research limitations/implications: Limitations include a focus on a specific demographic, and future research should explore other industry sectors and external factors like government policies

Practical implications: This research has implications for prospective entrepreneurs and business actors to be able to develop a culture of sharing knowledge sources and implementing AI to accelerate innovation for sustainability.

Originality/value: While there has been substantial research on sustainable entrepreneurship, studies that comprehensively integrate artificial intelligence, knowledge resources, frugal innovation, and entrepreneurial personality traits remain scarce. Previous research tends to isolate the role of each of these variables in more specific contexts. This study aims to fill this gap by constructing a more holistic model that accounts for the complex interplay among these various factors in driving business sustainability.

Keywords: Knowledge, Artificial intelligence, Frugal Innovation, Entrepreneurship Sustainability

JEL codes: L26, M00, M, 54, O10, O30, O32, Q01

1. Introduction

Sustainable development is an endeavor to meet the needs of the present without compromising the ability of future generations to meet their own needs. The government is promoting green economic growth by focusing on sustainable natural resource management, environmentally friendly investments, and the appropriate use of technology. The success of these efforts is measured through the Green Economy Index (Gupta & Dharwal, 2022; Coordinating Ministry for Economic Affairs of the Republic of Indonesia, 2023; Neumann, 2022). The government is working to enhance opportunities for economic growth and innovation while addressing barriers to entrepreneurship. These efforts also aim to tackle fundamental societal issues, such as poverty, low-quality jobs in the informal sector, and the gap in digital access (Media, 2023; Sony, 2021). Indonesia currently has an entrepreneurship ratio of 3.47%, but to achieve developed nation status by 2045, a ratio of 12% of the population is needed. According to data from the Central Statistics Agency (BPS) in 2022, the youth population in Indonesia reached approximately 65.82 million, accounting for about 24% of the total population. This data highlights the significant potential of the Indonesian population to become entrepreneurs (Media, 2022, 2023). Environmentally-based entrepreneurship involves the development of new products and technologies to address environmental challenges. This concept emphasizes the importance of sustainability and supports environmental movements. Currently, there is growing consumer awareness and demand for eco-friendly products, making it crucial for entrepreneurs to take greater responsibility and understand the importance of running sustainable businesses (Albhirat et al., 2024; M. Gupta & Dharwal, 2022; Ramírez et al., 2019; Zhao et al., 2021). Sustainable practices in environmentally-based businesses face several challenges, including increased costs and time, a lack of suppliers, limited policies, insufficient knowledge, low participation and support, technological constraints, financial performance issues, and a lack of mindset shifts and interest in developing entrepreneurial potential (Ebolor et al., 2022; Hossain et al., 2023; Kurnia & Priyastiwi, 2024; Pedroso et al., 2023; Zhao et al., 2021). The changing business landscape has led to shorter product life cycles, technological lag, and increased global competition. As a result, companies must focus on various aspects to enhance their business efficiency, including speed, quality, price, innovation, and customer responsiveness, in order to achieve a competitive advantage (Darroch et al., 2015). Specifically, knowledge resources and innovation are considered essential for achieving competitive advantage and long-term success (Saqib & Satar, 2021; Wijaya & Suasih, 2020). Organization's capacity to absorb knowledge has a significant impact on its environmental performance. As a result, effective knowledge management, supported by employee expertise, can enhance corporate sustainability. Within the sustainability framework, knowledge management plays a key role in developing and utilizing knowledge resources in a way that integrates social, environmental, and economic considerations for long-term success (Arduini et al., 2024). Integrating knowledge management strategies with the organization's overall strategy is crucial to achieving sustainability in all areas (Davenport & Ronanki, 2018). There are two main sources of human knowledge: internal and external. The ability to generate knowledge from internal sources can drive individuals with certain personality traits to become more innovative and successful (AlMulhim, 2021; Erjavec et al., 2019; Shaukat et al., 2023). Knowledge positively influences investment decision-making among marginalized communities; the greater the knowledge, the better the investment decisions. While knowledge is crucial for innovation, the effects of knowledge sources from the perspective of SMEs and emerging markets have yet to be fully explained (AlMulhim, 2021; Kurnia & Priyastiwi, 2024; Lei et al., 2021). In the digital economy era, companies face both internal and external challenges to maintain their sustainability in the global market (Anwar, 2018; Khraishi et al., 2023; Li et al., 2018). Addressing these complex challenges requires technological expertise to develop both immediate and long-term solutions (Duan et al., 2019). Among the most promising solutions is

Artificial Intelligence (AI). AI-based communication enhances cost-effective global outreach and the efficient use of resources (Di Vaio et al., 2020; Wu, 2021). AI and Frugal Innovation (FI) can provide dynamic, data-driven solutions to tackle social challenges (Hossain et al., 2022; Wu, 2021). AI plays a role in connecting artificial technology with human and organizational knowledge, enabling managers to make smarter and more efficient decisions (Schneider & Leyer, 2019; Sousa & Rocha, 2019). However, AI is still primarily used for data processing, with applications in education or healthcare, and remains limited in its ability to predict the future (B. B. Gupta et al., 2023; Vecchiarini & Somià, 2023; Wu, 2021). To improve AI implementation, businesses must consider legal, ethical, educational, and societal factors (Kaplan & Haenlein, 2019, 2020). AI is revolutionizing business practices and influencing management, offering more competitive and sustainable products and services (Garbuio & Lin, 2019; Govindan, 2024; Lei et al., 2021; Wright & Schultz, 2018). In the face of financial and knowledge limitations, companies are expected to produce products and services that meet customer needs through FI (Hossain, 2021; Hossain et al., 2023). Research findings suggest that FI promotes sustainability and addresses global challenges, such as driving economic growth, meeting social needs, and protecting the environment (Albert, 2022; Khan & Melkas, 2020). However, government policies and knowledge resources about FI in developing countries are often insufficient to support FI activities. FI is mainly driven by large institutions, while certain groups tend to view its use as a symbol of low social status (Ebolor et al., 2022; Shahid et al., 2023). One of the challenges in implementing FI is managing technology, particularly in the context of competition in AI, which makes it difficult for small businesses and startups to access affordable technology. Although in 2023, Indonesia's digital economy was valued at approximately Rp. 1,283 trillion, with projected growth to Rp. 1,705 trillion in the coming years (antaranews.com, 2024). Studies show that access to technology, especially AI, plays a crucial role for small businesses. The use of AI in FI can enhance the impact and effectiveness of innovation from various perspectives (Govindan, 2024; Thakare et al., 2022). Additionally, millennials are driven to invest due to the ease of accessing information through technology and cost efficiency (Priyastiwi, 2023). Research on FI, when combined with AI and knowledge sharing, can leverage the transformative power of emerging technologies to create sustainable solutions. While prior studies on environmentally-based entrepreneurship have been conducted, there is no comprehensive model integrating AI, knowledge sources, FI, and personality traits from the perspectives of SMEs and developing countries. Existing research on AI focuses on data processing, education, and healthcare (B. B. Gupta et al., 2023; Vecchiarini & Somià, 2023). Studies on FI often relate to economic changes and environmental challenges (Pedroso et al., 2023; Shahid et al., 2023, 2023). However, there has been no research on the role of knowledge sources and personality traits in FI. FI has typically been seen as either an antecedent or an outcome and no study has yet used FI as a mediator (Hossain et al., 2022). Personality traits have been treated as antecedents in previous literature, but no research has applied personality traits as a moderating factor in models involving FI, knowledge sources, AI, and sustainability. This study uses the RBV-JDR theoretical framework, applying mediation-moderation analysis to develop a comprehensive model of environmentally-based entrepreneurial sustainability. The research contributes by creating a comprehensive approach to overcoming entrepreneurial barriers and challenges. The objectives of this study are as follows: First, to investigate the influence of knowledge sharing on frugal innovation and its impact on the sustainability of student-led businesses engaged in technology. Second, to examine the effect of AI on frugal innovation and its impact on business sustainability. Third, to test the influence of knowledge sharing and AI on business sustainability, with frugal innovation as a mediator. Fourth, to examine the moderating role of personality traits in the relationship between frugal innovation and the sustainability of student entrepreneurship.

2. Theoretical Background and Hypotheses Development

The theoretical approaches used in this research are the Resource-Based View (RBV) and the Job Demands-Resources (JDR) model. RBV focuses on the strategic assets and competencies, emphasizing their financial and economic impacts to identify, utilize, and implement sustainable environmental initiatives for achieving competitive advantage (Barney, 1991). This framework provides a theoretical basis for assessing FI and AI by highlighting the importance of valuable resources and capabilities (Kruesi & Bazelmans, 2023). The JDR model describes two main categories: job demands and job resources. Job resources include physical, psychological, social, and organizational aspects that support the achievement of work goals, reduce physical and psychological burdens, and encourage individual growth, learning, and development. One critical job resource is the ability and understanding to seek relevant knowledge (Bakker & Demerouti, 2007).

Entrepreneurs with a deep understanding of market needs can apply their creativity, adaptability, and risk-taking abilities to address challenges in resource-constrained environments (Karyaningsih et al., 2020). Knowledge source (KS) has emerged through the concept of knowledge management, defined as "the exchange of experiences, facts, knowledge, and skills across the organization" (Malik & Kanwal, 2018). KS is essential for enhancing business capabilities in the contemporary economy, promoting creativity and accelerating innovation within organizations (Azeem et al., 2021). Significantly, knowledge resources enable new business possibilities and empower employees to share information that addresses critical issues by developing new ways to improve workflows (Danish et al., 2014). KS acts as a key factor in maximizing an organization's ability to manage knowledge resources and helps individuals achieve business goals more efficiently (Yang et al., 2018). KS is a vital organizational resource for gaining competitive advantage (Wang & Noe, 2010). Therefore, the business revolution and workplace diversity necessitate knowledge-sharing activities to create opportunities that enhance staff self-efficacy, improve learning, and disseminate knowledge among relevant personnel. KS is closely linked to FI as it empowers individuals to identify opportunities, utilize limited resources, and develop affordable, scalable solutions (Karyaningsih et al., 2020). Organizations can apply frugal principles such as cost-effectiveness and simplicity to create innovative products and services for underserved markets (AlMulhim, 2021). Organizations can apply frugal principles such as cost-effectiveness and simplicity to create innovative products and services for underserved markets (Qin, 2024). Knowledge fosters the responsive development of FI by facilitating quick literacy, positive social impacts, and market adoption. An entrepreneurial mindset, combined with frugal innovation, often promotes sustainable solutions to meet various global challenges. Although several researchers have emphasized the importance of KS in driving overall innovation and improving organizational performance, the focus on the role of KS in Corporate Sustainable Development (CSD) remains limited (Abbas & Sağsan, 2019; Wang & Noe, 2010). Furthermore, research on the relationship between KS, innovation, and CSD is still scarce. Previous studies suggest that organizations rooted in knowledge-based operations are not only more innovative but are also better positioned to explore new opportunities for sustainability (Abbas & Sağsan, 2019). Dynamic organizations leverage technology to create new products or enhance existing ones and processes, thereby improving organizational performance from economic, environmental, and social perspectives (Anwar, 2018). While previous studies have shown that FI can be a solution to sustainability problems, its scope is still limited. The use of appropriate technology and frugal innovation is crucial for achieving sustainable development. Entrepreneurs with broad knowledge in various fields can create innovative and cost-effective products to address environmental challenges. Additionally, effective knowledge management and the ability to adapt to changing technology also play a significant role in driving cost-effective innovation (Bazyar et al., 2024; Rao & Liefner, 2023; Régnier, 2023). To address this gap, the current study analyzes the relationship between KS, FI, and sustainability. The hypotheses are stated as follows:

H1a: Knowledge sharing positively influences frugal innovation.

H1b: Knowledge sharing positively influences sustainability.
H1c: Knowledge sharing positively influences sustainability through frugal innovation.
H1d: Frugal innovation mediates the influence of sources of knowledge and artificial intelligence on green entrepreneurial sustainability.

Complex challenges in the business world require technological expertise to obtain immediate and long-term solutions. Among the most promising possibilities is AI, where machines can "learn from experience, adapt to new inputs, and perform tasks like humans" (Duan et al., 2019; Thakare et al., 2022). AI technology offers three main benefits: First, it enables the automation of essential but repetitive and time-consuming tasks, allowing humans to focus on higher-value work. Second, AI uncovers insights trapped in vast amounts of unstructured data that require human management and analysis. Third, AI can integrate thousands of computers and other resources to solve the most complex problems (Nishant et al., 2020). AI can support organizational processes aligned with individual cultures and practices to reduce the demand for natural resources and energy from human activities. The true value of AI lies not just in enabling individuals and societies to reduce energy, water, and land use intensity. Instead, its real value will be realized at a higher level by facilitating and promoting effective environmental governance (Govindan, 2024; Thakare et al., 2022). Moreover, AI can play a crucial role in frugal innovation by enabling affordable automation, personalized solutions, data analysis, and clearer services. Previous research has indicated that the potential of AI in FI can yield more beneficial, dynamic, and data-driven solutions to critical social challenges. AI allows frugal innovators to operate efficiently with fewer resources while addressing challenges in developing economies to provide impactful and measurable solutions. Additionally, AI is another vital factor that plays a central role in FI by connecting sensible devices and enabling data-driven solutions for organizations (Balogun et al., 2024). FI has empowered businesses to unleash the potential of innovative ideas and technologies by embracing simplicity, cost-effectiveness, and creativity FI has empowered businesses to unleash the potential of innovative ideas and technologies by embracing simplicity, cost-effectiveness, and creativity (Sarkar & Mateus, 2022). This concept has gained global recognition, ultimately benefiting not only developing countries but also inspiring sustainable solutions. Over the past few decades, research on frugal innovation has evolved from the need to address challenges in resource-constrained conditions, particularly in developing nations. However, the role of AI in FI warrants attention as it offers numerous opportunities to enhance the impact and effectiveness of frugal solutions from various perspectives (Govindan, 2024). Research on the moderating role of Personality Traits (PT) in entrepreneurial sustainability is still quite limited, though several studies are relevant to this area. Previous studies have indicated that AI can shape how individuals with dark personality traits, such as Machiavellianism, narcissism, and psychopathy, perform in certain business and professional contexts. Additionally, other findings suggest that individual factors, including moral and spiritual obligations, strongly influence sustainable entrepreneurial intentions, both directly and indirectly (Harms et al., 2024; Javed et al., 2024). Therefore, the hypotheses for this study are as follows:
H2a: AI positively influences frugal innovation.
H2b: AI positively influences sustainability.
H2c: AI positively influences sustainability through frugal innovation.
H2d: Personality traits moderate the influence of sources of knowledge, artificial intelligence, and frugal innovation on green entrepreneurial sustainability.

3. Data and Methods

3.1. Research Design

This study utilizes a quantitative cross-sectional approach, collecting data from a group of individuals or

respondents at a specific point in time within one year. The methods employed are descriptive and correlational. The descriptive method begins by formulating research problems to explore or describe the social situation being studied comprehensively. It aims to provide a clear picture of the observed phenomena without manipulating or influencing variables. Meanwhile, the correlational method measures the degree to which variations in one factor relate to variations in another, using correlation coefficients as a measurement tool (Bougie & Sekaran, 2020).

3.2. Data Source

The data used includes primary data, directly collected from original sources to answer research questions. This data is gathered through interviews, surveys, or observations. In addition, secondary data, which is indirectly obtained from other sources, serves as supplementary information to fulfill data needs in this research (Bougie & Sekaran, 2020).

3.3. Population, Sample, and Sampling Technique

The study's population consists of all university students across Higher Education Institutions (HEIs). The sample is drawn from students residing in several provinces in Indonesia. The sampling technique used is non-probability sampling, specifically incidental sampling, where samples are selected based on availability and accessibility without considering measurable probabilities (Bougie & Sekaran, 2020).

3.4. Data Collection Techniques

Data was collected through interviews and distributing questionnaires to respondents. The questionnaire includes general respondent information and statements related to the research variables. The statements were measured using a 5-point Likert scale.

3.5. Research Variables

The independent variables in this study are knowledge sources, measured by 10 adapted items (Shahid et al., 2023). AI measured by 7 adapted items (Qin, 2024). The dependent variable is interest in environmentally-based sustainable entrepreneurship, measured by 8 adapted items (Alvarez-Risco et al., 2021). The mediating variable FI, is measured by 5 adapted items (Al-Omoush et al., 2024), and the moderating variable is personality traits, consisting of 15 adapted items (Song et al., 2023).

3.6. Data Analysis

The data analysis process is essential to ensure that the collected data, from both fieldwork and other sources, can be systematically analyzed and used to support research findings or informed decision-making. The data was tested and analyzed using Structural Equation Models (SEM) processed through Smart Partial Least Squares (SmartPLS) software. The steps for SEM-PLS testing are as follows:

3.6.1. Outer Model Analysis

The measurement of the outer model aims to test the validity and reliability of the variables, consisting of convergent validity, where the loading factor value between latent variables and their indicators is expected to be above 0.6. Next, composite reliability is used to measure construct reliability, with a reliability value greater than 0.6 indicating high reliability. Lastly, Average Variance Extracted (AVE) should have a minimum value of 0.5, indicating how well the construct is measured by its indicators (Hair et al., 2019, 2021).

3.6.2. Inner Model Analysis

The measurement of the inner model is used to test the relationships between latent constructs, including R-Square and Q-Square. R-Square is the coefficient of determination for endogenous constructs, where R-Square values can be classified as substantial (0.67), moderate (0.33), or weak (0.19). Prediction relevance (Q-Square) assesses how well the model predicts the outcome, with categories of small (0.02), moderate (0.15), and large (0.35). This test applies only to endogenous constructs with reflective indicators (Hair et al., 2019, 2021).

3.6.3. Hypothesis Testing.

Hypothesis testing is performed by examining the t-statistic and probability values (p-values). For a 5% alpha level, the critical t-statistic is 1.96 (Hair et al., 2021).

4. Results and Discussion

A total of 314 respondents will be included in this research. The characteristics of the respondents are divided by gender, with 67.8% female and 32.2% male. Most respondents are between the ages of 20 and 25 (75.5%). Another characteristic is the respondents' monthly income, where 54.8% earn less than IDR 1.000.000 per month. Lastly, based on entrepreneurial experience, 54.5% of the respondents have had experience owning or running a business (Table 1. Respondent Characteristics).

Characteristics		Amount	Percentage
Gender	Women	213	67.8
	Man	101	32.2
Age	< 20 years	67	21.3
	20 - 25 years	237	75.5
	26 - 30 years	3	1
	31 - 35 years	2	0.6
	> 35 years	5	1.8
Monthly income	< 1.000.000	172	54.8
	1.000.000 - 2.000.000	105	33.4
	2.000.000 - 3.000.000	27	8.6
	3.000.000 - 4. 000.000	5	1.6
	> 5.000.000	5	1.6
Have a business/Have run a business	Yes	171	54.5
	No	143	45.5
Total		**314**	**100**

Table 1. Respondent Characteristics

The validity of the model is assessed by examining the loading factor or outer loading. An indicator is considered valid if the loading factor exceeds 0.6. Based on the analysis results, invalid indicators, such as some items under the SoK and AI variables, were removed due to having a loading factor below 0.6. After removing these invalid indicators, the final results showed that all remaining items met the validity criteria with loading factor values above 0.6 (Figure 1. Loading Factor Value).

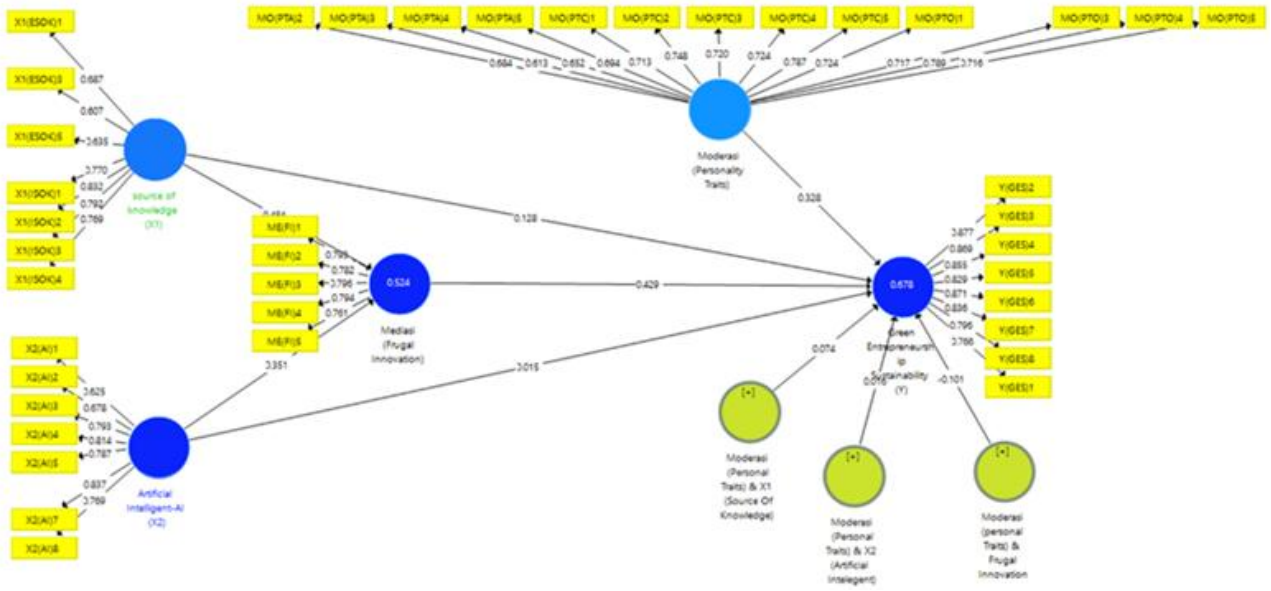

Figure 1. Loading Factor Value

The reliability of the variables was tested using Composite Reliability (CR), which must exceed 0.7, and Average Variance Extracted (AVE), which must be greater than 0.5. The analysis results showed that all research variables, including independent, mediating, and moderating variables, had CR values above 0.7 and AVE values above 0.5. This indicates that the measurements for each variable are reliable and demonstrate good reliability (Table 2. CR and AVE Result).

Variable	CR	AVE
AI	0.905	0.579
GES	0.950	0.703
FI	0.889	0.617
PT → SoK	1.000	1.000
PT →AI	1.000	1.000
PT	0.931	0.512
PT → FI	1.000	1.000
SoK	0.889	0.535

Table 2. CR and AVE Result

The R^2 value indicates how much of the variation in the dependent variable can be explained by the independent variables. Based on the analysis, the model shows an R^2 value of 0.67, meaning that variables such as SoK, AI, and FI explain 67% of the variation in GES, which is considered a strong effect. Q^2 is used to measure the predictive ability of the model. Q^2 value greater than 0 indicates that the variables and data can predict the model well. The obtained Q^2 value of 0.47 demonstrates that the model has good predictive relevance (Table 3. R^2 and Q^2 Test Results).

Variable	R^2	Q^2
GES	0.670	0.470
FI	0.521	0.312

Table 3. R^2 and Q^2 Test Results

The research findings support the first hypothesis, indicating that sources of knowledge have a

significant and positive impact on innovation. This indicates that an increase in knowledge sharing will drive higher levels of innovation, enabling companies to develop new solutions and improve their internal processes. The findings of this study also provide evidence that a strong knowledge-sharing culture within an organization is a key driver of innovation. The results show that when employees actively share their ideas, experiences, and knowledge, it creates a unique synergy. This synergy sparks the emergence of new creative ideas, innovative problem-solving, and the development of better products or services. In other words, the more knowledge sources are shared, the richer the organization's 'pool of ideas,' increasing the chances of generating innovation. This research emphasizes the importance of building a dynamic learning community within organizations. When employees feel safe and encouraged to share their knowledge, it not only enhances individual performance but also fosters innovation, which can provide a competitive edge. Successful organizations are those that can fully leverage their intellectual potential. By facilitating knowledge sharing and its resources, they can also create a more innovative and adaptable work environment that responds effectively to change. Furthermore, by facilitating the exchange of knowledge and resources on green technology, environmental regulations, and industry best practices, organizations can accelerate the transition toward more sustainable business models. Additionally, sharing knowledge resources can help identify new business opportunities related to sustainability, such as the development of eco-friendly products or sustainability consulting services. Innovation, particularly in the areas of products and processes, acts as a catalyst for adopting environmentally friendly practices. Innovative companies tend to develop more efficient products and services that have a lower carbon footprint. Furthermore, innovation in production processes enables companies to optimize the use of natural resources, reduce waste, and enhance operational efficiency. Innovation not only drives business growth but also serves as a powerful tool for achieving sustainability goals. As a key driver of sustainability, innovation allows companies to create more sustainable products and services, thereby reducing their negative environmental impact while meeting the increasing demands of environmentally conscious consumers. Additionally, innovation can foster the creation of new markets and open up more sustainable business opportunities. In a broader context, sustainability-oriented innovation can contribute to sustainable development and societal well-being. Moreover, investing in R&D becomes essential as companies need to develop new technologies, alternative raw materials, and more environmentally friendly product designs. Thus, innovation is not merely a result of creative processes but also a product of systematic efforts to find more sustainable solutions. Companies committed to sustainability must allocate adequate resources to R&D activities to promote ongoing innovation. The findings of this study align with the Resource-Based View (RBV) and Job Demands-Resources (JDR) theories, which emphasize the importance of knowledge sharing and its resources as key factors in performing tasks and, in turn, driving innovation. These results also support previous research, which highlights the crucial role of knowledge in fostering innovation and sustainability (Azeem et al., 2021; Karyaningsih et al., 2020; Qin, 2024; Thakare et al., 2022; Yang et al., 2018).

The findings of this study supporting the second hypothesis, clearly demonstrate that AI has become a major catalyst in driving innovation across various industrial sectors. With its ability to automate repetitive tasks and analyze data on a large scale, AI frees human resources to focus on more creative and strategic work. AI-supported business process automation not only enhances operational efficiency but also generates valuable data that can be leveraged to identify new innovation opportunities. This enables companies to develop products and services that are better tailored to customer needs while shortening product development cycles. The results of this research confirm that AI plays a central role in driving product and service innovation. Advanced machine learning algorithms allow companies to analyze customer preferences in greater depth, enabling them to create more personalized and relevant

products and services. Additionally, AI can be utilized to design new, more complex, and innovative products, such as autonomous vehicles or virtual assistants. Thus, AI not only improves efficiency but also opens up new market opportunities and drives business growth. The research findings indicate that AI's predictive analysis capabilities are key to fostering innovation. By predicting market trends, consumer behavior, and potential risks, companies can make better and more proactive business decisions. AI-supported predictive analysis also enables companies to identify previously untapped innovation opportunities. This allows organizations to develop products and services that not only meet current market needs but also anticipate future demands. AI has paved new avenues for companies to optimize the management of natural resources. With its capability to analyze data on a large scale, AI can identify patterns of energy and raw material consumption that are inefficient. This enables companies to implement more targeted conservation measures. For instance, AI can be utilized to optimize equipment maintenance schedules, reducing downtime and minimizing energy waste. Additionally, AI can assist in managing supply chains more efficiently, thereby reducing travel distances and the carbon emissions associated with transportation. AI has become a catalyst in the development of more environmentally friendly products and services, while also designing more efficient and durable products. It can help identify alternative raw materials that are more sustainable and optimize product designs to minimize waste and provide innovative solutions to complex environmental issues, such as water pollution. AI can also predict equipment failures before they occur, reducing downtime and minimizing environmental impacts. Furthermore, AI can monitor air and water quality in real time, enabling companies to take corrective action before serious environmental damage occurs. In this way, AI can significantly aid companies in achieving their sustainability goals. The findings of this study support previous research that has stated that the utilization of AI plays a crucial role not only in specific fields but also in broader areas, including business management (Duan et al., 2019; Govindan, 2024; Hossain et al., 2023; Nishant et al., 2020).

The results of this study provide strong evidence that individual personality traits play a crucial role in driving the adoption of sustainability strategies in entrepreneurship. The findings indicate that entrepreneurs with a high level of openness to experience are more likely to embrace new ideas and innovations, including sustainable business practices. Responsibility is also an important factor, as responsible entrepreneurs tend to be more concerned about the social and environmental impacts of their businesses. Additionally, the willingness to take risks significantly contributes to this dynamic, as entrepreneurs who are bold enough to take risks are more likely to try new sustainability-oriented business strategies, even if they involve uncertainty and challenges. This study yields intriguing results, indicating that individual characteristics, such as personality, do not have a significant impact on the extent to which knowledge sources, AI and FI can drive sustainability in entrepreneurship. This implies that external factors, such as access to knowledge, technology, and cost-effective business approaches, play a more dominant role in promoting sustainable business practices. In other words, while personality may influence an entrepreneur's motivation and interests, these external factors provide more concrete tools and resources to actualize sustainable business practices. The results of this study indicate that FI plays a crucial role as a mediator between SoK and AI in driving GES. These findings support our hypothesis that FI acts as a partial mediator in this relationship. This means that FI is not only influenced by SoK and AI but also actively contributes to enhancing GES. In other words, while SoK and AI have a direct impact on GES, their influence is strengthened when companies adopt frugal innovation. This suggests that FI can maximize the benefits of knowledge sources and AI technology in achieving sustainability goals. The results also highlight the significant advantages of FI, such as helping companies translate knowledge acquired from various sources, including scientific research and industry best practices, into innovative solutions that are suitable for local contexts and constrained

resources. FI enables companies to optimize their use of AI technology more effectively by focusing on simple, cost-effective, and sustainable solutions. FI facilitates the integration of technological innovation with daily business practices, thereby creating sustainable added value.

5. Conclusions

This research demonstrates that Source of Knowledge (SoK), Artificial Intelligence (AI), and Frugal Innovation (FI) have a positive impact on Green Entrepreneurial Sustainability (GES). SoK and AI foster innovation, which in turn enhances sustainability in green entrepreneurship. Personality Traits also contribute positively to GES, although they do not moderate the relationship between SoK, AI, and FI towards GES. Additionally, FI has been proven as a partial mediator that strengthens the influence of SoK and AI on GES, indicating that cost-effective innovation plays a significant role in creating sustainable entrepreneurial practices.

The practical implications of this research are to foster innovation and sustainability, companies should cultivate a knowledge-sharing culture and implement effective knowledge management systems. Encouraging collaboration and information exchange enriches the organization's idea pool and drives innovative solutions. The adoption of AI can accelerate innovation by improving operational efficiency and enabling the creation of products and services that better meet customer and market needs. FI should be a core strategy for achieving business sustainability, especially for resource-constrained companies. FI allows organizations to optimize technologies like AI with simple yet effective approaches. Entrepreneurship ecosystems should foster personality traits like openness to experience and risk-taking to expedite the adoption of sustainability strategies.

This research also contributes theoretically by reinforcing the Resource-Based View (RBV) and Job Demands-Resources (JDR) theories. These theories emphasize the importance of resources, especially knowledge and innovation, in achieving organizational performance and sustainability. The findings also enrich the literature on the role of Frugal Innovation in entrepreneurial sustainability and highlight the role of AI as a key catalyst in driving innovation across sectors. One limitation of this study is that it does not specify a particular industry sector, thus the findings may not be fully generalizable to sectors with varying levels of technology adoption or innovation. Additionally, the study falls short of considering the influence of external factors, such as government regulations or market access, which can also impact entrepreneurial sustainability. Suggestions for future research include exploring the impact of SoK, AI, and FI across various industry sectors to determine if the findings are consistent across sectors. Future studies should consider external factors such as environmental policies or government incentives that can drive the adoption of sustainable practices. Additionally, for established businesses, developing programs that foster openness and risk-taking can strengthen the impact of personality on innovation and sustainability.

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