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Sustainability Literacy in Indonesian Higher Education: An Interrelationship Hierarchical Model

Viqi Ardaniah[a*], Zakiyah Dania Billah[b], Lastiko Endi Rahmantyo[a], Andika Wisnujati[c], Peter Ardhianto[d]
[a] *Universitas Airlangga, Indonesia*
[b] *Universitas Dinamika, Indonesia*
[c] *Universitas Muhammadiyah Yogyakarta, Indonesia*
[d] *Universitas Katolik Soegijapranata, Indonesia*

Sustainability literacy motivates higher education institutions to perform sustainable practices; however, improving sustainability literacy through the resilience of the education system and adaptive learning technology has not been sufficiently addressed in previous studies. This study aims to identify the attributes of sustainability literacy in Indonesian higher education. This study offers a valid set of seven aspects and twenty-two criteria implementing a bibliometric analysis and the fuzzy Delphi method. A fuzzy decision-making trial and evaluation (FDEMATEL) is employed to analyze the validated attributes and to determine interrelationships among the attributes. This procedure allows qualitative information to be converted into numerical data and a diagram indicating the attribute interrelationship. The results of this study revealed that adaptive learning technology, resilience of the education system, sustainability-focused courses, and sustainability innovation are the causal attributes of sustainability literacy. Financial literacy, sustainability consciousness, and global citizenship curriculum are the affected attributes of sustainability literacy. Some vital criteria for improving sustainability literacy in HEs include educational innovation, educational technology, and resilience in HE. Hence, this study provides theoretical and managerial contributions based on the proposed attributes.

Keywords: adaptive learning technology, FDEMATEL, higher education, sustainability literacy, resilience

1 Introduction

In Indonesia, higher education (HE) institutions have followed a world university ranking in which sustainability indicators are considered. However, generally, there has been a significant gap in the sustainability indicators. Areas such as Zero hunger, good health and wellbeing, industry innovation, inequalities, peace, and justice are left behind. Particularly, assessments on environmental impact and social impact as the indicators have weighed less than 2% of all university performances. For instance, Jusuf et al. (2020) found that universities' environmental impact contributes only 1% to the overall evaluation. This 1% spreads evenly from emission efficiency, climate science, sustainability courses, net zero commitment, policy on sustainability investment, student society focused on environmental sustainability, to research centers with sustainability focus. Similarly, the social impact in HEs also contributes only 1%, including equality diversity and inclusion policy, health provision on campus, disability support, outreach, and community engagement. Moreover, HEs are found to not fully implement sustainability-focused business processes due to a lack of commitment and sustainability understanding across HE parties covering top and middle management, internal stakeholders such as lecturers, students, registrars and external stakeholders (Nuryana, 2022). These situations indicate that sustainability practices in HE need to be improved and understanding towards sustainability holistically cannot be avoided. Hence, promoting sustainability literacy (SL) leads to improving the university's performance on the sustainability indicators. The failure to develop SL has led to inadequate use of technologies in the learning process, slow-moving innovation, low environmental awareness, insufficient sustainable attitudes and competencies (Kinzer, 2021).

In the literature, SL attributes consisting of aspects and criteria are primarily identified from environmental aspects, social concerns including environmental knowledge and behavior, and educational purposes (Khan et al., 2013; Kinzer, 2021). Zaman et al. (2024) emphasized the need to

Correspondence: viqiardaniah@fib.unair.ac.id

measure environmentally friendly behavior to enhance SL in education. Vallée (2023) proposed that graduates and students have a crucial role in promoting solutions to environmental issues. The graduates and students are also considered to be agents of change for sustainability in HEs. Cavalcanti-Bandos et al. (2021) suggested an interconnected area between social aspect and finance to encourage pedagogical analysis, professional training, and students-focused teaching learning process. However, some challenges to increase SL among HE academicians remain, leading to the failure of sustainable practices in education (Chou et al., 2019). SL is an emerging issue which indicates appealing gaps that require to be comprehensively identified. Benavot et al. (2024) argued that the education system needs to be resilient for articulating SL into all management levels where all parties need to be equipped with abilities of anticipation, prevention, prediction for uncertainty conditions. De Genaro Chiroli et al. (2023) and Fenwick et al. (2022) suggested that SL can be viewed through the capability to recover from unexpected conditions, supported by a supportive institutional system and flexibility implementation. Ciampa (2017) recommended the use of various technologies and applications among academicians as technology users for the success of SL adaptation. Therefore, the resilience of the education system and adaptive learning technologies are demanded to develop SL in HE.

Prior studies have described SL through several approaches. The development of SL in educational institutions requires a national certification to ensure the institutions adopt sustainability in teaching learning culture. Luo and Cheng (2022) claimed that a quantitative analysis can reveal the SL attribute selection including economic aspects such as financial resources, financial literacy, and business model. Cincera et al. (2023) have employed a mixed approach to identify beliefs, motivations, and strategies regarding how learners engage in sustainability activities indicating SL. In the context of sustainability, when literacy is underestimated, it leads to unsustainable practices at both individual and institutional levels (Goldman et al., 2018). However, prior studies have neglected the selection of the causal attributes from social, economic, environmental aspects, contributing to SL development and the interrelationship of SL attributes. For example, Cincera et al. (2023) and Goldman et al. (2028) focused environmental concern through certification, curriculum and informal programs to enhance sustainability practices. Kong et al. (2023) and Hu (2023) emphasized the incorporation between artificial intelligence (AI) and social sustainability to improve SL without taking into account economic concern. Thus, this study proposes a hierarchical model to determine SL attributes by initially applying a bibliometric analysis, employing the fuzzy Delphi method (FDM) to validate the attributes from a database and the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method, as similarly employed by Tseng, et al. (2021), to draw the interrelationship of attributes that can enhance SL (George-Ufot et al., 2017; Hu, 2023). Further, this study aims to:

- Identify the cause-effect interrelationship of SL aspects and criteria;
- Select the criteria for enhancing SL in HEs.

Theoretically and practically the current study offers contributions to educational institutions and HEs by highlighting the integration of sustainability practices to achieve long-term sustainable goals. (1) Theoretical contributions are to develop a set of SL attributes and provide the hierarchical model which indicates a causal relationship among the attributes for improving SL. (2) Practical contributions are presented in the form of practical guidelines on how academicians and HEs can promote SL to articulate sustainable practices.

The structure of this study is classified into four sections. Section one provides the SL background and highlights the urgency of promoting SL by presenting aspects from prior studies. Section two emphasizes the SL theoretical framework along with the proposed aspects and criteria as attributes. Section three presents the bibliometric analysis, the FDM, and the FDEMATEL methods. Section four discusses theoretical and practical implications, limitations and conclusions.

2 Theoretical Framework

Sustainability literacy (SL) is defined as a set of abilities, attitudes, competences, dispositions, and values necessary to thrive in the challenging conditions of the outside world while actively attempting to slow down the rate of deterioration as much as is practical (Kinzer, 2021). The idea behind SL is to equip people with understanding, capabilities, and beliefs necessary to be totally engaged in performing sustainability practices and creating resourceful decisions. Thus, all parties in educational

institutions, particularly educators, need to adopt SL as a concept to be taught for students who become graduates or influential professionals and managers within businesses, governments, and any industrial sectors. This emphasizes the notion that being literate in sustainability is having the ability to critically analyze and reinterpret society and oneself in order to improve social aspects while preserving or strengthening the environmental systems that support life (Cincera et al., 2023). However, addressing SL among academicians encounters a difficult task because curriculum and new pedagogies require to be redesigned and embedded with abilities in global citizenship (Kinzer, 2021).

Educational institutions face difficulties in incorporating sustainability into the curriculum because of the specialized nature of its scientific programs and disciplines. There is a need toward comprehensive policies, procedures, and plans when education curricula must offer an integrative viewpoint on societal, individual, and professional demands while upholding ethical standards. Filho et al. (2024) highlighted that the incorporation between SL and HE has been restricted by a lack of sources. Furthermore, Vallée (2023) claimed that the main barriers to educational institutions for building SL include a lack of planning and concern, minimal continuity and less implementation of sustainable solutions.

Following a review of SL literature, this study proposes a vital attribute set of aspects and criteria to support SL improvements among academicians. Prior studies have suggested pedagogical aspects in terms of curriculum redesign, courses and learning outcome development to disseminate SL among HE academicians (Filho et al., 2024; Khan & Handerson, 2020; Lysenko et al., 2019). Cincera et al. (2023) and Hu (2023) highlighted the need for innovative technologies to be used for spreading SL. In addition to educational and technological aspects, Babajide et al. (2023) suggested that the financial aspect is important. Financial knowledge and skills lead academicians to mitigate unanticipated finance issues since sustainable finance is required to establish SL. However, the resilience aspect when building SL has not been considered. Resilience plays a significant role in directing and guiding SL in HE (Benavot et al., 2024; Fenwick et al., 2022). Hence, this study attempts to integrate the aforementioned aspects to enhance SL including sustainability innovation, sustainability focused courses, financial literacy, resilience of education system, sustainability consciousness, global citizenship curriculum, and adaptive learning technology.

2.1 Proposed SL attributes

In the context of SL, Denoncourt (2020) defines sustainability innovation (A1) as comprising updated notions, means, or approaches and providing more appropriate ways to overcome challenges, obstacles, meet new improvements, and address uncommunicated demands. This innovation is motivated by the provision of newly, originally developed products, procedures, technologies, business models, capabilities for massage analysis and evaluation. Additionally, sustainability innovation demands HEs to invite external stakeholders in integrating three key features including creativeness, innovativeness, and technical capability. These main features form an HE innovative curriculum design that encourages academicians to have skills in entrepreneurship both at practices and theories (Herman & Bossle, 2020). Moreover, innovation and creativity are also needed to enhance entrepreneurship networking for HEs to gain more funding sources in relation to infrastructure development (Luo & Cheng, 2022). Chuo et al. (2019) believed that effective and better use of resources motivate HEs to sustain and promote academics to be involved in sustainability (Chou et al., 2019).

Sustainability focused courses (A2) have been considered as one way to promote SL in classes of any field (Khan & Henderson, 2020). HE institutions are gradually introducing sustainability into all areas of campus life including their courses, research, and operations. A major initiative in this area is the creation of sustainability focused courses, intended to offer students with the values, knowledge, and abilities needed for tackling complex sustainability issues (Zhang et al., 2022). However, not only is education for sustainable development hardly incorporated into the current curriculum or campus procedures, but also political initiatives for sustainable development from the government are not considered. In addition, despite being labelled as sustainability-focused courses, none of them entirely satisfied the requirements set forth by the university, and many instructors are unaware of the course status or sustainability policy (Khan & Henderson, 2020).

Financial literacy (A3) denotes the capability to make an effective decision by processing economic statistics and creating financial planning, counting wealth accumulation for better future financial conditions (Siddik et al., 2023). It is an essential lifelong skill that should be taught to any age at the earliest stage. Financial literacy is crucial for living a successful and independent life, promoting economic growth, and supporting digitalized services or products (Babajide et al., 2023) It is also important for the survival of educational industries and social interactions for human capital development both developed and developing countries (Sharma et al., 2016). Additionally, this form of literacy pertains to the ability for recognizing and evaluating financial products based on their stated sustainability-related features (Luo & Cheng, 2022).

Resilience of the education system (A4) is an interdisciplinary concept. According to Benavot et al., (2024), resilience is the capacity of individuals, social groups, or systems to anticipate and react to disruptive conditions in a manner that reduces vulnerability and promotes sustainability. This includes an education system's capacity to manage crises and provide continuous education despite disruptions. The resilience of an education system is the capacity to bounce back from adversity, adapt to difficulties, and maintain high performance under pressure. These definitions place a strong emphasis on the value of flexibility, continuity, and consistent performance in building a resilient educational system that can endure a range of obstacles. Additionally, De Genaro Chiroli et al., (2023) interpret resilience as "engineered resilience," which emphasizes the capacity of systems to sustain diversity and flexibility in the face of disruptions and effects brought on by climate change. Another way to characterize resilience is as an ever-evolving process that is a part of complex social-environmental systems.

Resilience of the education system demands HEs to equip students from social-economically disadvantaged backgrounds with self-efficacy skills and a sense of belonging (Fenwick et al., 2022). This skill refers to HE students' capability to improve themselves with determined attempts. Benavot et al. (2024) emphasized students must have a sense of belonging as global citizens that require students to resolve unforeseen challenges during and after their study. HEs prepare students to have critical thinking and develop problem-solving skills towards uncertain and complex sustainability issues by embedding SL in particular courses (Davidson et al., 2020). However, such efforts are less effective to improve SL when wide-ranging strategies toward sustainability at university level are still lacking (Cavalcanti-Bandos et al., 2021). Hence, strategies on students' skill development need to strengthen the resilience of the education system.

Sustainability consciousness—SC (A5) is a comprehensive concept that includes attitudes, behaviors, and knowledge related to the environmental, economic, and social aspects of sustainable development (Cincera et al., 2023; Goldman et al., 2018). Research on SC has largely concentrated on educational settings, with students being the primary subjects. Studies indicate that education for sustainable development in educational institutions can have a modest positive impact on learners' SC, though this effect may wane in higher grades. Pre-service educators exhibited significantly lower SC levels compared to upper secondary learners, and their levels were similar to those of other undergraduate learners. These results underscore the necessity for expanding SC education beyond the institutions into professional environments to effectively achieve the sustainable development goals.

The global citizenship curriculum (A6) requires students actively to be problem solvers. Recent studies highlight the increasing significance of the global citizenship curriculum in higher education for preparing students in a connected world (Soriano et al., 2022). Thus, global citizenship education needs to be incorporated through study abroad programs, coursework, and various university initiatives. Academic leaders acknowledge the necessity of cultivating global citizens, although its implementation can be challenging (Soriano et al., 2022). The notion of global citizenship has shifted from civic engagement to global engagement, with higher education institutions playing a pivotal role in developing cross-cultural competencies in students. Prior studies underscore the ongoing efforts to develop and implement global citizenship curricula in higher education, responding to the needs of an increasingly globalized society and workforce. Incorporating global citizenship into the curriculum is one way to increase SL in HE which contributes to the graduates having a well-paid job and building stable and prosperous societies.

Adaptive learning technology (A7) can be used to increase learners' interests towards sustainability in employing their sustainability knowledge for social, economic, and environmental

issues. Davidson et al. (2020) emphasizes the importance of experiential learning in sustainability education, particularly for addressing complex problems. Technologies inspire educational institutions to find sustainable innovative solutions, foster transformative learning towards artificial intelligence, engage in educational technology, and apply an analysis on strength, weakness, opportunity, and threat (Buhl et al., 2019; Kong et al., 2023; Lysenko et al., 2019; Romero-Gutierrez et al., 2016). The idea of adaptive learning technologies can be utilized to speed up performance and dynamically adapt to individual talents to improve experiential learning. When combined with practical learning, these technologies have the potential to greatly enhance students' sustainability literacy. Furthermore, Ciampa (2017) found that adaptive learning plays a significant role in relation to improving literacy on sustainability issues, for example, bridging various technologies and capability of technology users, highlights the great potential in combining practical learning and technologies.

Students, as the agent of change and technology users, have the capacity to personalize and adjust the existing technology in the learning process to improve their SL (Lysenko et al., 2019). The more diverse the learning technologies students engage with, the greater the learning outcomes can be achieved. When students effortlessly employ learning technologies, they are more engaged and enthusiastic in courses. Hu (2023) associated learning technology with how students implement artificial intelligence technology to facilitate academic performance to become more efficient, optimized, independent and life-long learning. Chou et al. (2019) highlighted that students during their study are required to be more exposed to the use of developed technology and strategies in solving problems in future work life. Such exposures encourage students to have breakthrough competence and creativity for encountering sustainability issues after they graduate from HE.

Table 1 presents the proposed SL attributes. The aspect indicates how the SL is framed through literature. The criteria show more specific indicators than the aspect. These criteria support the aspects to frame SL. In other words, building SL requires aspects, and each aspect is constructed through its criteria.

Table 1. Proposed SL Attributes

Aspect		Criteria		Description	References
A1	Sustainability Innovation	C1.	Digital literacy	Understanding and skill to employ digital based applications	(Chou et al., 2019; Sharma et al., 2016; Siddik et al., 2023)
		C2.	Digital technology	Utility that is employed for work-associated practice	
		C3.	Media Literacy	Capability for accessing, analyzing, assessing, and creating message	
		C4.	Technology adoption	Accepting and adopting technology 4.0 for product and services	
A2	Sustainability focused courses	C5.	Problem based learning	Students involved at working on particular cases to enhance active learning	(Hermann & Bossle, 2020; Zizka & Varga, 2021)
		C6.	Sustainability science	Science about sustainability to comprehend the complexity of physical, environmental, economic, and social system	
A3	Financial literacy	C7.	Digital economy	Process to digitalize services and production	(Babajide et al., 2023; Sharma et al., 2016)
		C8.	Social capital	Social interactions in which all assets lead to human capital improvement	
		C9.	Financial knowledge	One form of literacy about financial matters	

	Aspect	Criteria	Description	References
A4	Resilience of education system	C10. Education for sustainable development	Integration between sustainability skills and competencies by study program	(Benavot et al., 2024)
		C11. Collaborative learning	Learning process requires students to work in a group for a concept discussion	
		C12. Resilience in HE	Capability of recovering, adapting, and maintaining performance under uncertainties	
		C13. Sustainability competencies	Competency to comprehend, mitigate unpredictable changes, prepare mentality for interdisciplinary issues	
A5	Sustainability consciousness	C14. Environmental attitude	A belief that determines someone's behavior toward environment	(Cincera et al., 2023; Goldman et al., 2018)
		C15. Environmental awareness	An understanding that underlies the behavior toward environmental effects	
		C16. Environmental education	Education that provides individuals to engage in environmental problem solving	
		C17. Environmental literacy	Cognitive and affective values, self-efficacy, attitudes, skills, sensitivity, competence of individuals towards environment	
A6	Global citizenship curriculum	C18. Information technology	Utilization of computer systems, hardware and software, programming and data to develop sustainability capability of institutions	(Soriano et al., 2022)
		C19. HE for sustainable development	HE contribution to graduates for a well-paid job, stable and sustainable job.	
		C20. Knowledge sharing	One way to disseminate information through skills	
A7	Adaptive learning technology	C21. Educational innovation	Strategy to overcome educational problems while involving various parties	(Lysenko et al., 2019; Romero-Gutierrez et al., 2016)
		C22. Artificial intelligence	Machines or computer-based system controlling humans' tasks	
		C23. Educational technology	Technologies used to facilitate learning process	
		C24. SWOT analysis	A planning that facilitates HEs to encounter challenges	

3 Method

3.1 Proposed Method

This study employs three methods to obtain the interrelationship hierarchical model. The first step is to conduct a bibliometric analysis. Then, the fuzzy Delphi method is employed to validate the collected attributes from the database. Finally, the Fuzzy DEMATEL (FDEMATEL) is applied to visualize the causal interrelationship among the SL attributes (Hu, 2023). George-Ufot et al., (2017) have stated that the FDEMATEL can evaluate aspects that affect problems in industries, determine the most critical aspects in a hierarchy, confirm interdependence among attributes.

3.2 Bibliometric Analysis

This study employs the bibliometric analysis as this method provides high comprehension toward the subject, wider coverage, systematic key thematic attributes (Arya et al., 2024; Filho et al., 2024). The bibliometric analysis presents an evaluation of network structure, the past-to-future understanding towards the issues or subject matter. Such an analysis provides a greater scope and inclusiveness in overviewing the significant studies over years. Hence, this study employs such an analysis to identify SL attributes from a database that has not been fully addressed in prior studies. This initial step involved collecting the attributes from Scopus database, selected for it is considered to have the widest coverage of publications on related themes (Filho et al., 2024). The analysis was conducted using 1.6.11-VOSviewer version. Some keywords were inserted in search engines; "sustainable literacy OR sustainability literacy OR environmental literacy AND higher education institution AND university AND institute". Inclusion criteria include a review article, journal article, English language, and open access. The software can extract information including titles, abstracts, and keywords of SL.

After the aspects and criteria as attributes were collected, they were transformed into a questionnaire to collect linguistic preferences from experts. The experts were selected based on some criteria. The criteria include a) holding either the top or middle management in the universities or institutes, b) participating in one of any projects for sustainability in the form of research or community development, c) having a minimum of 10-year experience in HE, d) spreading in three Indonesian regions, from west, center, to east regions of HE. Hence, this study involved 30 experts from various HEs positioned as Head of Division, Dean or Vice Deans, Head of unit at the university level.

3.3 FDM

Guided by Bui, et al. (2024), considering k refers to the number of experts' decision-making group, while l denotes the number of attributes, the analytical step starts from expert m, who is asked to give his judgments on the importance degree of attribute t as d=(x_{mt}; y_{mt}; z_{mt}), m=1,2,3,…,k; t=1,2,3,…,l, in which d_t is the weight of t described as d_t=(x_t; y_t; z_t) with x_t=min(x_{dt}), $y_t = \left(\Pi_l^k y_{dt}\right)^{1/k}$ and z_t=max(z_{mt}). Then, the linguistic preferences from the experts are converted into $\left(\Pi_l^k y_{dt}\right)^{1/k}$ Triangular fuzzy numbers (TFNs) seen in Table 2 (George-Ufot et al., 2017; Tseng, et al., 2021).

Table2. Linguistic Preferences Description in FDM

Linguistic preferences	Triangular fuzzy numbers (TFNs)
Very High Influential (VHI)	(0.75, 1.0, 1.0)
High Influential (HI)	(0.5, 0.75, 1.0)
Influential (I)	(0.25, 0.5, 0.75)
Less Influential (LI)	(0, 0.25, 0.5)
Not Influential (NI)	(0, 0, 0.25)

The convex combination values use γ as:

$$\begin{gathered} u_t=x_t - \gamma(z_t - y_t), \\ d_t=d_t - \gamma\,(y_t - \gamma x_t), \\ y=1,2,3,\ldots, l \end{gathered} \tag{1}$$

in which γ= [0,1] presents if, as Bui, et al. (2024) also employed, the experts have optimistic tendency or pessimistic tendency. γ= 0.5 normally denotes a neutral condition.

Similarly, as with Tseng, et al. (2021), the fuzzy score is converted into exact numbers F_t as:

$$F_t = f\left(u_t, d_t\right) = \sigma\left[u_t + \left(1-\sigma\right)d_t\right] \tag{2}$$

where σ indicates the experts have a positive equilibrium assessment.

Then, the threshold is gained as $\theta = (\sum_{s=1}^{l} F_t)/l$ = is used to obtain the threshold and filter the valid attributes from the initial set.

If $F_t \geq \theta$, attribute y is valid. If not, it is removed.

Additionally, similar to Bui, et al. (2024), a direct interview with the experts is done to sort out the SL keywords and determine the attributes for analyzing SL. The experts can share their understanding and opinions for the final SL aspects and criteria.

3.4 Fuzzy DEMATEL

Considering the total of experts in the decision-making group is β, their evaluation is described as 3_{hi}^{β}; β^{th} denotes the member's statement concerning how the h^{th} attribute influenced the i^{th} attribute according to their personal evaluation (Bui, et al., 2024). These evaluations must be transferred into the TFN $\left(R_{hi}^{\beta}, S_{hi}^{\beta}, T_{hi}^{\beta}\right)$ to acquire a crisp value for further computation. The equation (8) is employed to normalize the TFN seen in Table 3.

Table 3. TFN and Linguistic Preferences for Fuzzy DEMATEL

Scale	Linguistic preferences	Corresponding triangular fuzzy numbers (TFNs)
1	Very high Influential	(0.1, 0.1, 0.3)
2	High Influential	(0.1, 0.3, 0.5)
3	Moderate Influential	(0.3, 0.5, 0.7)
4	Less Influential	(0.5, 0.7, 0.9)
5	Not Influential	(0.7, 0.9, 1.0)

$$\begin{aligned} A_{hi}^{\beta} &= \frac{\left(R_{hi}^{\beta} - R_{hi}^{\beta}\right)}{\sigma} \\ B_{hi}^{\beta} &= \frac{\left(S_{hi}^{\beta} - S_{hi}^{\beta}\right)}{\sigma}, \sigma = \left(maxT_{hi}^{\beta} - minR_{hi}^{\beta}\right) \\ C_{hi}^{\beta} &= \frac{\left(T_{hi}^{\beta} - minT_{hi}^{\beta}\right)}{\sigma} \end{aligned} \tag{3}$$

The normalized values of the left $\left(VL_{hi}^{\beta}\right)$ and right $\left(VR_{hi}^{\beta}\right)$are obtained by employing Equation 4.

$$\begin{aligned} VL_{hi}^{\beta} &= \frac{Y_{hi}^{\beta}}{\left(1 + Y_{hi}^{\beta} - X_{hi}^{\beta}\right)} \\ VR_{hi}^{\beta} &= \frac{Z_{hi}^{\beta}}{\left(1 + Z_{hi}^{\beta} - Y_{hi}^{\beta}\right)} \end{aligned} \tag{4}$$

Adopting the equation as below generates the crisp values.

$$CV_{hi}^{\beta} = \frac{\left[VL_{hi}^{\beta} \times \left(1 - VL_{hi}^{\beta}\right) + \left(VR_{hi}^{\beta}\right)^2\right]}{\left(1 - VL_{hi}^{\beta} + VR_{hi}^{\beta}\right)} \tag{5}$$

Guided by Bui, et al., (2024), the crisp values derived from all experts are integrated by employing Equation 6.

$$CV_{hi} = \frac{\sum_{h,i=1}^{\beta}(CV_{hi}^{\beta})}{\beta} \quad (6)$$

The crisp values are arranged in a direct relation matrix $D = [CV_{hi}]_{p\times p}$. P refers to representing the total of proposed criteria. To normalize the direct relation matrix, Equation 7 is applied.

$$D' = \lambda \times D, \lambda = \frac{1}{\max\limits_{1\le h\le p}\sum_{n=1}^{p} CV_{hi}} \quad (7)$$

This study employs Equation 8 to calculate the total relation matrix (T_m).

$$T_m = D' \times (\zeta - D')^{-1} = [\overline{\mathrm{CV}}_{hi}]_{p\times p} \quad (8)$$

where ζ is the unit matrix.

Obtaining the vectors D and R for the causal effect diagram is generated by applying Equation 9 and 10.

$$D = \left[\sum_{h=1}^{p}(\overline{\mathrm{CV}}_{hi})\right]_{p\times 1} = [\overline{\mathrm{CV}}_{hi}]_{p\times 1} \quad (9)$$

$$R = \left[\sum_{i=1}^{p}(\overline{\mathrm{CV}}_{hi})\right]_{1\times p} = [\overline{\mathrm{CV}}_{i}]_{1\times p} \quad (10)$$

The causal effect diagram is drawn from the vertical axis and the horizontal axis. The D - R represents the vertical, while the D + R represents the horizontal one. There are two areas of the diagram. The top area indicates the driving attributes called the causal group. The causal group shows the area that needs more attention and improvement to achieve SL. The bottom area shows the effect group indicating less importance.

4 Results

4.1 Bibliometric analysis results

The bibliometric analysis generated fifty-seven attributes. The 57 attributes were classified into seven aspects, namely A1-sustainability innovation (Denoncourt, 2020), A2-sustainability focused courses (Khan & Henderson, 2020), A3-financial literacy (Siddik et al., 2023), A4-resilience of education system (Benavot et al., 2024; Chiroli et al., 2023), A5-sustainability consciousness (Cincera et al., 2023), A6-global citizenship curriculum (Soriano et al., 2022) and A7-adaptive learning technology (Davidson et al., 2020).

4.2 FDM results

Table 4 indicates the initial criteria that are declined and renamed. The first column shows the complete number of criteria, while the last column presents the renamed criteria as they are confirmed. For example, digital literacy initially is named Criteria 2. After FDM, criteria 2 is renamed as C1. Digital technology is named Criteria 7. After FDM, Criteria 7 is renamed as C2. This applies to all confirmed criteria.

Table 4. FDM sorting out the SL attributes

Criteria	u_t	d_t	F_t	Decision	Renamed
Criteria 1digital transformation	0.000	0.500	0.250	Declined	
Criteria 2 digital literacy	0.147	0.918	0.496	Confirmed	C1
Criteria 3 information literacy	0.000	0.500	0.250	Declined	
Criteria 4 digital learning	0.000	0.500	0.250	Declined	
Criteria 5 digital competence	0.000	0.500	0.250	Declined	
Criteria 6 education 4.0	0.000	0.500	0.250	Declined	
Criteria 7 digital technology	0.141	0.907	0.489	Confirmed	C2
Criteria 8 media literacy	0.149	0.922	0.498	Confirmed	C3
Criteria 9 technology adoption	0.142	0.909	0.490	Confirmed	C4
Criteria 10 entrepreneurship education	0.000	0.500	0.250	Declined	
Criteria 11 entrepreneurial intention	0.000	0.500	0.250	Declined	
Criteria 12 problem-based learning	0.147	0.918	0.496	Confirmed	C5
Criteria 13 climate change education	0.000	0.500	0.250	Declined	
Criteria 14 responsible management education	0.000	0.500	0.250	Declined	
Criteria 15 sustainability science	0.126	0.878	0.470	Confirmed	C6
Criteria 16 digital economy	0.000	0.854	0.427	Confirmed	C7
Criteria 17 education policy	0.000	0.500	0.250	Declined	
Criteria 18 economic development	0.000	0.500	0.250	Declined	
Criteria 19 social capital	0.000	0.831	0.416	Confirmed	C8
Criteria 20 financial knowledge	0.000	0.804	0.402	Confirmed	C9
Criteria 21 education for SD	0.133	0.892	0.479	Confirmed	C10
Criteria 22 collaborative learning	0.139	0.902	0.486	Confirmed	C11
Criteria 23 resilience in HE	0.137	0.899	0.484	Confirmed	C12
Criteria 24 sustainability competencies	0.134	0.893	0.480	Confirmed	C13
Criteria 25 system thinking	0.000	0.500	0.250	Declined	
Criteria 26 digital pedagogy	0.000	0.500	0.250	Declined	
Criteria 27 transformative learning	0.000	0.500	0.250	Declined	
Criteria 28 work integrated learning	0.000	0.500	0.250	Declined	
Criteria 29 digital society	0.000	0.500	0.250	Declined	
Criteria 30 climate change	0.000	0.500	0.250	Declined	
Criteria 31 environmental attitude	0.000	0.861	0.430	Confirmed	C14
Criteria 32 environmental awareness	0.000	0.872	0.436	Confirmed	C15
Criteria 33 energy efficiency	0.000	0.500	0.250	Declined	
Criteria 34 renewable energy	0.000	0.500	0.250	Declined	
Criteria 35 environmental knowledge	0.000	0.500	0.250	Declined	
Criteria 36 environmental behavior	0.000	0.500	0.250	Declined	
Criteria 37 environmental education	0.000	0.870	0.435	Confirmed	C16
Criteria 38 indigenous knowledge	0.000	0.500	0.250	Declined	
Criteria 39 environmental literacy	0.000	0.876	0.438	Confirmed	C17
Criteria 40 environmental management	0.000	0.500	0.250	Declined	
Criteria 41 environmental sustainability	0.000	0.500	0.250	Declined	
Criteria 42 global citizenship	0.000	0.500	0.250	Declined	
Criteria 43 information technology	0.133	0.892	0.479	Confirmed	C18
Criteria 44 knowledge management	0.000	0.500	0.250	Declined	
Criteria 45 global citizenship education	0.000	0.500	0.250	Declined	
Criteria 46 HE for sustainable development	0.130	0.886	0.475	Confirmed	C19
Criteria 47 curriculum development	0.000	0.500	0.250	Declined	
Criteria 48 knowledge sharing	0.129	0.883	0.474	Confirmed	C20
Criteria 49 social sustainability	0.000	0.500	0.250	Declined	
Criteria 50 community engagement	0.000	0.500	0.250	Declined	
Criteria 51 educational innovation	0.139	0.903	0.486	Confirmed	C21
Criteria 52 technology-enhance learning	0.000	0.500	0.250	Declined	
Criteria 53 learning environment	0.000	0.500	0.250	Declined	

Criteria	u_t	d_t	F_t	Decision	Renamed
Criteria 54 information and communication technology	0.000	0.500	0.250	Declined	
Criteria 55 Artificial intelligence	0.128	0.881	0.472	Confirmed	C22
Criteria 56 educational technology	0.129	0.883	0.474	Confirmed	C23
Criteria 57 swot analysis	0.139	0.903	0.486	Confirmed	C24
	Threshold		0.341		

4.3 FDEMATEL

In this section, two tables are presented. Table 5 indicates the aspects' prominence and relation axis for the cause-and-effect group indicating SL. Table 6 reveals the criteria' prominence and relation axis for the cause-and-effect group indicating SL.

Table 5. SL aspect's prominence and relation axis for the cause-and-effect group

Aspect	D	R	D+R	D-R
Aspect 1	11087.9	10866.8	21954.7	221.1
Aspect 2	10779.0	10771.8	21550.8	7.2
Aspect 3	10073.9	10771.8	20845.7	-698.0
Aspect 4	11462.1	10725.9	22187.9	736.2
Aspect 5	10247.0	10911.8	21158.8	-664.8
Aspect 6	10090.4	10898.5	20988.9	-808.1
Aspect 7	11593.5	10877.0	22470.4	716.5
Max			22470.4	736.2
Min			20845.7	-808.1
Average			21593.9	-70.0

Table 6. SL criteria's prominence and relation axis for the cause-and-effect group

	D	R	D+R	D-R
Criteria 1	1006.9	991.0	1997.9	16.0
Criteria 2	1003.6	980.9	1984.6	22.7
Criteria 3	1021.3	980.9	2002.3	40.4
Criteria 4	1018.5	994.9	2013.4	23.6
Criteria 5	887.0	1010.8	1897.7	-123.8
Criteria 6	890.7	1027.4	1918.1	-136.7
Criteria 7	775.6	1070.8	1846.4	-295.2
Criteria 8	790.8	1083.8	1874.7	-293.0
Criteria 9	772.9	1026.5	1799.4	-253.6
Criteria 10	1020.9	1002.6	2023.5	18.3
Criteria 11	1044.5	998.6	2043.0	45.9
Criteria 12	1045.8	1037.9	2083.7	7.9
Criteria 13	1052.1	997.8	2049.9	54.3
Criteria 14	813.7	998.9	1812.6	-185.2
Criteria 15	786.6	1011.7	1798.3	-225.0
Criteria 16	772.6	1031.6	1804.2	-259.0
Criteria 17	794.8	1030.5	1825.3	-235.7
Criteria 18	939.9	1006.1	1945.9	-66.2
Criteria 19	928.7	998.5	1927.2	-69.8
Criteria 20	931.6	1013.5	1945.1	-81.9
Criteria 21	1105.0	1051.7	2156.7	53.3
Criteria 22	1005.7	1051.7	2057.4	-46.0
Criteria 23	1034.1	1023.5	2057.5	10.6
Criteria 24	1029.4	1023.0	2052.4	6.3
Max			2156.7	54.3
Min			1798.3	-295.2
Average			1954.9	-82.2

Figure 1. The causal interrelationship of SL aspects

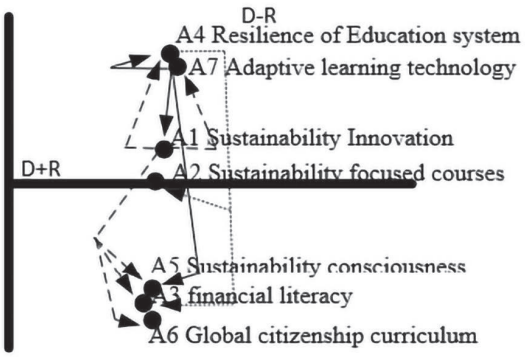

Figure 1 is derived from table 5. Its computation is employed to draw a diagram of causal interrelationship of SL aspects. The crips values of A1-A7 aspects are normalized based on equations (7) – (8). The aspect classification is determined based on a cause-and-effect diagram employing equations (9) – (10). With reference to Figure 1, The diagram is drawn applying (D+R) and (D-R). The results indicate that resilience of the education system, adaptive learning technology sustainability innovation and sustainability focused courses belong to the causal group. Meanwhile, sustainability consciousness, financial literacy, and the global citizenship curriculum belong to the effect group.

Figure 1 presents that the causal attributes to sustainability literacy. Particularly, the strongest interrelationship presented in a straight arrow line (→) is seen on adaptive learning technology (A7) to resilience of education system (A4), and sustainability consciousness (A5), sustainability innovation (A1) and sustainability focused courses (A2). The moderate interrelationship presented in a dash arrow (**- - ->**) is viewed from the resilience of the education system (A4) to sustainability focused courses (A2) and financial literacy (A3). Meanwhile, the weakest interrelationship in a round dot arrow can be seen in sustainability innovation to the resilience of the education system (A4), adaptive learning technology (A7), global citizenship curriculum (A6), sustainability consciousness A5, and financial literacy (A3).

Figure 2. The causal interrelationships of SL criteria

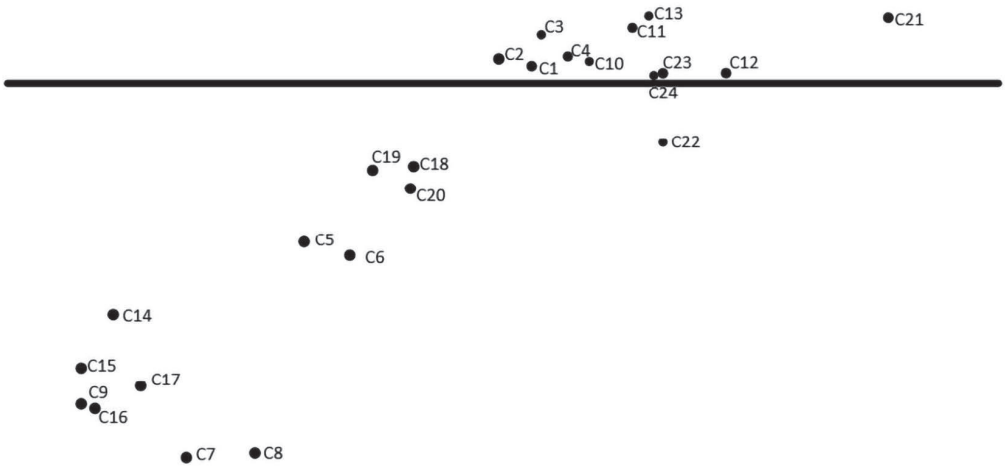

Figure 2 represents the causal interrelationship of SL criteria and it is derived from Table 6. There are 11 of 24 valid criteria in the top area of the diagram classified as the driving criteria for improving SL. The driving criteria consist of educational innovation (C21), resilience in HE (C12), educational technology (C23), SWOT analysis (C24), sustainability competencies (C13), collaborative learning

(C11), education for sustainable development (C10), technology adoption (C4), media literacy (C3), digital literacy (C1) and digital technology (C2). The criteria that are grouped in the bottom area include artificial intelligence (C22), information technology (C18), knowledge sharing (C20), HE for sustainable development (C19), sustainability science (C6), problem-based learning (C5), social capital (C8), digital economy (C7), environmental attitude (C14), environmental literacy (C17), environmental awareness (C15), financial knowledge (C9), and environmental education (C16).

5 Discussion

5.1 Theoretical implications

This study contributes to the literature by offering theoretical implication into the cause-effect relationship among the aspects of SL. The findings reveal that resilience of the education system (A4) followed by adaptive learning technology (A7), sustainability innovation (A1), sustainability focused curriculum (A2) are vital driving aspects of SL.

This study reveals that resilience of the education system is the most crucial aspect that influences SL improvement. This aspect needs to be highlighted as the basis for anticipating, preventing, withstanding, managing, overcoming unpredictive, or disruptive conditions in the education system (Benavot et al., 2024). Such an aspect suggests all internal parties in the education system including top management, educators, administrators, learners need to be educated and trained to have understanding and capability to encounter challenges and changes in the extent of SL. Improving the resilience of the involved parties enhances better performance of SL because not only the parties can adapt and mitigate the impacts from sustainability issues like economic, social, and environmental breakdowns, but also they can be actively responsive and participative and flexibly transformative from disadvantaged to advantaged conditions. Also, SL in the field of education demands well-established support systems from institutions, academic resilience, ability to rebound from disruptive social-economic and environmental conditions (Chiroli et al., 2023; Fenwick et al., 2022). This finding emphasizes that the support system and ability of recovery should be enhanced, beginning from encouraging resilience of the education system and accelerating literacy for sustainability practices. Thus, assessment and evaluation towards resilience of the education system as well as management education to achieve SL need to be proposed.

Resilience of the education system takes into account how students actively increase their ability to perform behaviors for achieving outcomes or goals. In the context of SL, students are expected to have confidence, determination to foresee, adjust to changes, overcome hardships, predict risks that they experience in future (Benavot et al., 2024). Particularly, HE students develop their lifelong learning skills such as being optimistic, motivated, persistent when disruptions emerge. Students are expected to socially and emotionally prepare themselves for uncertain changes, explore potential for coping strategies in sustainability issues that take place before or after students graduate. For instance, after graduating from HE, students are involved in group-decision making, social equity implementation, and shared understanding among communities. Thus, building the resilience of the education system from students' perspective remains a critical priority to increase SL in HE.

Adaptive learning technology refers to any technologies employed to encounter unpredictable changes that need adapting learning towards SL. Technology motivates all parties in education institutions to develop solutions on sustainability issues, create transformative learning, perform social-environmental practices holistically and ethically (Davidson et al., 2020). This result highlights the relationship between the education system, learning exposures, and pedagogical applications. Adaptive learning plays a great role in relation to improving literacy on sustainability issues, for example, bridging various technologies and capability of technology users (Ciampa, 2017). This aspect provides opportunities for employing e-learning processes or online learning which could facilitate educational institutions to shift towards sustainable practices. Adaptive learning technology encourages the institutions to improve their SL in terms of skills, knowledge, attitudes, habits, and values on social, environment and economy. Technologies that can be flexibly adapted in learning provide solutions to increase SL.

The learning technology in the form of AI applications encourages HE students to think creatively with a sustainability-oriented mindset. Such applications facilitate students with diverse learning

pace, unique needs, interests to be more active and participative in classrooms (Hu, 2023). On one hand, adaptive learning technology could help HE to improve SL by supporting AI-based learning for HE students and transforming traditional classrooms into completely linked networks. This shift allows students to study independently from anywhere and anytime and provides them with an adjusted and flexible learning process that can be extended after students complete their study. On the other hand, using adaptive learning technology from students' perspective needs continuous investment because the learning technology is not only applied during the period of study, but also after the completion of study. Updating the technology into advanced requires financial resources. However, incorporation between adaptive learning technology and HE systems relying on students' participation still enables learning outcomes to be effectively achieved (Goldman et al., 2018).

Sustainability innovation is considered a driving aspect of SL. This study offers evidence that incorporating social and environmental issues into a decision-making process leads human resources in the education system at all levels to have innovations (Denoncourt, 2020). Therefore, the need to improve innovative ideas from human resources is critical and this can be accomplished when educational institutions have established a good business process. The business process should encourage human resources to be more self-reliant and proactive in bringing better innovative thinking. However, establishing the business process triggers innovative ideas in the context of sustainability innovation requires collaboration, capacity, arrangement between the sustainability plans and goals. Therefore, there is an urgency to link the SL with the business process in the education system which is in line with the sustainability goals.

Sustainability focused courses are viewed to be vital for articulating SL. The SL articulation should take into account the need to redesign courses that are preceded by the redesigned curriculum along with syllabus, expected learning outcomes and quality assurance of learning process (Zhang et al., 2022). This aspect emphasizes that learning outcomes must represent the underlying sustainability goals because all learners are required to be equipped with skills of critical thinking and problem solving for any current social, economic, environmental issues. Not only are learners expected to have such skills, but also educators are demanded to have flexibility, adaptability, creativity in embedding sustainability issues in courses they teach.

5.2 Practical implications

This section presents the managerial implications of the study. The main criteria that affect the SL in HEs include educational innovation (C21), resilience in HE (C12), and educational technology (C23). Further practical strategies which assist the HEs are described.

Educational innovation (C21) is important to identify educational needs towards sustainability issues that can improve SL performance. In the context of higher education, the need of identification must integrate the innovation target, its scope, and stakeholders. External and internal stakeholders of HE are encouraged to build partnerships in the form of social, economic, environmental activities that indicate sustainability awareness, knowledge, attitude, and sustainability behaviors. In particular, the sustainability behaviors represent sustainable consumption patterns and environmentally friendly preferences. The problem is that in the process of identifying the educational needs toward sustainability, environmentally friendly behaviors, sustainability knowledge and attitudes of the stakeholders are not considered. This study recommends that all stakeholders provide innovative ideas for promoting environmentally friendly behaviors in the HE system such as creating learning outcomes and graduate profiles that indicate sustainability competencies and designing sustainability-based curriculum. Hence, promoting SL requires capabilities to sufficiently generate innovations that improve sustainability practices in HEs. Good coordination among the stakeholders is advised to contribute to understanding sustainability issues and increase a great number of educational innovations.

Resilience in HE (C12) refers to the need that academicians in HE institutions consisting of top management, educators, administrators, and students are equipped to have knowledge and skills. Such understanding and skills are concerned with more creative and survival attributes to encounter external pressures. Prior to SL, academicians need to build their individual resilience through emotional well-being and emotional intelligence during disruptive conditions. After the emotional well-being of academicians is built, they need to identify uncertainty resulting from unexpected

disruptive conditions, provide coping strategies, and predict the rebound impacts of the undergone strategies in order to establish resilience in HEs. This study recommends the HE academicians conduct regular training, more exposures, and simulations on how unpredictable circumstances are overcome and how a recovering mechanism is established for resilience in confronting social, economic, and environmental shocks. The training and simulations increase academicians' future orientation, adaptive skills, personal engagement through ethics, responsibilities, emotions, motivations, and solidarities. These actions can improve SL performance through resilience in HE.

Educational technology (C23) called EdTech concerns the use of technology by academicians in HE to facilitate the educational process in terms of teaching learning. This criterion particularly considers literacy among educators that integrate technology with sustainability practices in the educational processes. The integration of technology in daily-based works at all levels requires training and adaptations to achieve professional development, capacity of educators and to enhance educational outcomes of learners. However, this criterion has not been attained in practice because SL is not regarded as a strategic factor to articulate sustainability in HE. Such EdTechs as learning management systems (LSM), educational apps, assessment tools for increasing sustainable education are less adequately implemented than expected due to less motivation from educators. Educators in HE should be provided with more incentives, rewards, grants to facilitate them in employing EdTech in the teaching learning process. The LSM, apps, and tools should be designed in a more user-friendly mode. Increasing the role of educators in Edtech as a part of promoting SL becomes more crucial.

6 Limitations

Sustainability in Indonesian HE has been developed in the absence of literacy among academicians leading unsustainable practices, attitudes, behaviors in the daily work basis and building a gap in SL. A SL model that concerns the interrelationship of some attributes is demanded as HE has a vital role in promoting SL to all parties, from both internal and external parties. This study offers 24 criteria classified into 7 aspects as part of SL attributes considering social, economic, and environmental issues. A hierarchical method to collect SL attributes is employed. The bibliometric analysis is applied to generate SL attributes from the database. The FDM is adopted to sort out invalid attributes involving various experts' judgments. The FDEMATEL is used to draw the causal interrelationships among SL attributes and determine which attributes can enhance SL.

The results of this study indicate that 24 criteria are classified into seven aspects consisting of sustainability innovation, sustainability focused courses, financial literacy, resilience of the education system, sustainability consciousness, global citizenship curriculum, and adaptive learning technology. The driving aspects that affect SL improvement are resilience of the education system, adaptive learning technology, sustainability innovation and sustainability focused courses. The most significant criteria for improving HE in practice include educational innovation, resilience in HE, and educational technology. These criteria need to be addressed by HE to increase SL among academicians.

This study theoretically and practically provides contributions. A valid set of SL attributes is proposed and a hierarchical model is created to present guidelines for leading the sustainability practices. By determining the cause-effect interrelationships of SL attributes, the important aspects are proposed; the resilience of the education system serves as the most important aspect that must be built at the earliest stage of SL development. Practically, HE should prioritize educational innovation and technology as well as resilience and provide an action plan guideline for stakeholders, top management, educators, and students as active agents in SL promotion. Prioritizing the three criteria and providing the guidelines can contribute to raising sustainability knowledge, shaping sustainability attitude, building sustainability behavior and habits.

This study has some limitations. First, the SL attributes are generated from Scopus as a single database, leading to such a limited perspective as social, economy, and environment. Hence, the hierarchical model of SL may not be comprehensive. Further studies should take into account more databases which enrich SL attributes from different perspectives for example governance and technology. Second, the number of experts is very limited in HE. Future study is recommended to invite more HEs and experts with more requirements, representative areas. More various experts can offer more comprehensible judgements on SL issues. Third, more various types of HE institutions are

involved including private, public, autonomous HEs. The SL performance of each HE can be affected by different funding and policies from the related HE institutions. The next study shall consider these aspects in assessing SL.

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