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Sustainability dimensions in enhancing the energy and resource efficiency of big data systems

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ABSTRACT

Big data systems are essential for many businesses to grow, leveraging the vast amounts of data they generate and access. However, big data systems are plagued by significant sustainability challenges. Thus, this study aims to identify metrics that can measure the sustainability of big data systems. This research conducted a comprehensive literature review to identify five key sustainability dimensions: technical, environmental, economic, social, and individual. Then, a set of 29 metrics corresponding to these dimensions was developed. To ensure the relevance and applicability of these metrics, an expert validation session was carried out with five experts in the big data field. The validation process confirmed the appropriateness of our proposed metrics and modification take place. The findings of this study present 30 metrics upon experts' validation that could enhance the sustainability of big data systems, offering meaningful insights for researchers and practitioners aiming to enhance resource and energy efficiency in this domain.

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1. INTRODUCTION

Big data refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze [1], [2]. Precisely defining the term big data is quite elusive as many studies define it according to the suitability of contexts [3]. Big data is best defined in the context of information technology as a vast amount of data that is generated globally from a variety of sources, including social media, healthcare, and companies [4]. It is evident that data is exploding and this is the reason why big data is characterized as volume, velocity, variety, and veracity [5]. Recently, the number of V's has increased where value and variability have been added to make up to 6 V's [6]. The data explosion has demanded the need for a system called big data system which is defined as a data-centric system that handles the explosion of data in big data [7]. Moreover, big data systems also function as distributed systems that consist of duplicated processing nodes, mirrored storage, and frequently carrying out operation tasks using shared cloud infrastructure by employing different technologies such as structured query language (SQL), not only SQL (NoSQL), and NewSQL [7], [8].

Big data systems have become the backbone of modern businesses, especially in making smarter decisions [9]. However, big data systems present a pressing sustainability challenge. The data generated is not only huge but complex which makes analyzing it a most challenging task [1], [7], [10]. This also causes hurdles in data processing in big data systems [11] and it strains a high amount of energy as massive volumes of data are being processed [12]. In addition, storage systems consume a high amount of energy and resources [13]. Although better data helps in saving energy and resources, managing them requires physical processes [14]. It necessitates large-scale data centres that extensively use energy and resources [13], [15]. Thus, green performance metrics are needed in building energy-efficient data centres [16]. Adapting green cloud architecture and green storage systems has been proposed to reduce the worsening impact of data storage in data centres [17]. Additionally, inefficient use of resources is the main reason for high energy consumption in cloud data centres which are widely used by big data systems [18], [19]. In response to these challenges, the concept of sustainability has gained increasing prominence in the realm of big data systems.

For decades, sustainability has been a wide topic that plays a vital role in multiple fields. Collectively, the term 'sustainability' is broadly defined as the capacity to endure for humans and the potential for long-term maintenance [20]. Sustainability is also described as the ability to be maintained at a steady level without exhausting natural resources or causing severe ecological damage [21]. Energy and resource efficiency have been identified as the main components of sustainability in the literature. Energy efficiency is defined as "keeping usage of energy and its impact low" [22]. Resource efficiency is defined as "amounts and types of resources used by a product when performing its function to meet sustainability requirements [23]. Hence, energy efficiency is essential and it can be achieved by reducing energy usage [20] meanwhile resource efficiency is vital in systems handling huge volumes of data such as big data systems [10].

Inefficient consumption of energy indeed poses a noteworthy challenge to sustainability [13]. Bolstering this, inefficient resource utilization has emphasized a growing environmental concern [24]. Concerning this, sustainability challenges associated with big data systems need intensive attention as they consume a high amount of energy and resources [14]. A proactive step towards sustainability was initiated by proposing effective energy efficiency (EEE) and effective resource efficiency (ERE) to explore fresh perspectives and possibilities of green metrics for growing big data [13]. They insisted on the significance of energy and resource efficiency especially for big data systems and data centres. Another researcher intended to identify the green metrics for big data systems and aim to optimize their energy usage for environmental concerns [17]. The sole limitation of this study is they adapted general green metrics to test the energy efficiency of the big data systems where they were not specifically identified for big data systems.

Besides, the literature also addressed energy-efficient wireless networks as a need and a highlighting issue in big data [25]. Conversely, traffic-based models have been proposed as a solution for the lack of energy efficiency in big data centres [26]. In connection with this, a glaring gap can be witnessed that rarely attention has been given to encompassing energy and resource efficiency in big data systems which stresses an immediate solution for a sustainable big data system. Thus, investing in sustainability by encouraging energy efficiency is crucial [22]. Furthermore, an energy-efficient system would also contribute to resource efficiency [22], and achieving it prevents energy wastage of a system [27].

On the other hand, a significant number of researchers in the field of software engineering have successfully proposed and implemented sustainability to make software products and processes green and sustainable. Regrettably, when it comes to big data systems, a scarcity of studies is conducted to solve the sustainability issues that are inherent in them. Thus, the main objective of this study is to identify the dimensions and metrics that contribute to enhancing the sustainability of big data systems. Drawing inspiration from the successes in software engineering, this study embarks on a systematic literature review (SLR) as the research method to identify the underlying sustainability issues in big data systems and attempts to propose five sustainability dimensions namely technical, environmental, economic, social, and individual to enhance the energy and resource efficiency of big data systems.

Following this, an expert validation with experts in the field of big data was conducted. Their feedback and insights were incorporated into refining the proposed dimensions and metrics to ensure their validity and relevance. Then, modifications take place according to their comments before proceeding to data collection. The findings and insights of this research contribute meaningfully to the body of knowledge in the realm of big data, benefiting both academicians and practitioners. This study not only focuses on technical issues but also paves the way for a sustainable future in big data systems. The remainder of this paper is formatted as follows. Section 2 reviews related work in the field of big data and sustainability. Section 3 detailed the research methodology, including the SLR, instrument development, and expert review. Section 4 presents the proposed solution followed by a discussion of the findings in section 5. Section 6 concludes the paper by summarizing key insights suggesting directions for future research and mentioning the limitations of this study.

2. RELATED WORKS

Numerous studies have delved into the realm of big data, majority have focused on dealing with its privacy and security aspects and effective solutions has been suggested by [3], [18], [28]-[30]. A security model has been proposed to secure organization's data stored in big data [31]. Apart from this, the data quality in big data also was given broader attention in literature [32], [33]. The identified research voids in the literature concerning big data prompted the motivation for this study, drawing inspiration from the field of software engineering to propose the five sustainability dimensions. The justification for this study's motivation is elaborated upon in this section. Included below are several literatures works on software sustainability that contribute to the context of this study.

The prevailing model that has been broadly used is the generic sustainable software star model (GS3M) [34]. A lack of studies considers sustainability dimensions in the aspect of software process and product, yet this model presents a clearer vision of sustainable software by discovering all five sustainability dimensions. Several metrics were highlighted in this study such as knowledge/skills, perdurability, low cost, and profitability. Moreover, an intensive focus on green and software sustainability to ensure its durability was given in [35]. As mentioned in this study, it is important to develop software that could sustain viable in the environment. Thus, they integrated sustainability dimensions and waste management into software development life cycle (SDLC) phases to support the development of tolerable software while contributing to a greener environment.

The green software elements and measurement model has been developed in [20]. The issue that has been highlighted in the paper is software extensively impacting the environment negatively and rarely studies focus on greening software products. It is stated that the urge to produce energy and resource efficiency software is increasing. As informed by previous research, constrained efforts were made in greening software products [20]. According to the research, greening software products are crucial to ensure the perdurability of software in the aspect of sustainability. Thus, they have identified seven green measurements namely productivity, cost reduction, usability, employee support, tool support, energy efficiency, and resource efficiency. All these factors are claimed to be retrieved from the three sustainability dimensions namely environmental, economic, and social. This approach was unique as it contributed to green software products from the aspect of sustainability. Plus, lack of attention to sustainability within software quality has been highlighted in [27], [36]. They focus on estimating and specifying sustainability quality attributes. Thus, they conducted a SLR to identify sustainability attributes for software quality.

Deliberating sustainability in the initial stage of design would prompt the IS designers to be acquainted with non-functional requirements from the aspect of sustainability [37]. Thus, a theoretical model for sustainability has been developed as a paradigm for future green IS design by considering environmental, economic, social, and cultural sustainability. Similarly, to tackle serious environment and social issues, a conceptual model was proposed to boost an organization's ecological sustainability [38]. This model integrated three sustainability components namely eco-effectiveness (environmental), eco-efficiency (economic), and eco-equity (social). This study emphasized the practitioners should forecast the impact of their information systems design on the environment before implementing it and emphasized the importance of IS contribution to the ecological sustainability.

Nevertheless, the importance of technical sustainability in software development has been overlooked [39]. To fortify this viewpoint, maintainability which is one of the main factors of technical sustainability is causing obstacles but still it was rarely focused [40]. Intriguingly, this paper adapts Karlskrona's Manifesto for sustainability design which said as a centerpiece for sustainability designs to bring a solution. A detailed literature review was presented and discussed cross-disciplinary software sustainability for software-intensive systems. Besides, an idea of implementing the sustainability in the requirement phase of software development was highlighted [41].

An extensive number of studies have discovered the dimensions of technical, environmental, economic, and social yet rarely attention was given to the individual sustainability [42]. This study viewed individual sustainability from two different aspects. Solutions were proposed to improve the well-being of the software engineers as it is equally important as other sustainability dimensions. Nonetheless, the human behaviour plays crucial role in preventing the damage to the environment and green practices is considered as the best solutions [43].

Collectively, the related works on sustainability dimensions were elaborated above. Therefore, the five sustainability dimensions is believed to enhance the sustainability of big data systems. Each of these dimensions has its specific metrics which could be used to measure the energy and resource efficiency of big data systems.

3. METHOD

The method of this study involves three important processes. A SLR was conducted followed by an instrument development and lastly expert review session. The detailed explanation of this research methodology has been explained in this section.

3.1. Systematic literature review

A SLR has been conducted based on guideline provided in [44]. Based on the literature review analysis, five sustainability dimensions and its metrics was proposed. Three phases of SLR takes place namely planning, executing and reporting and these procedures of SLR has been practiced in [44]-[46].

3.1.1. Planning

Planning is the commencement of the SLR process and the activities include identifying the research context, outlining review protocols, and formulating precise research questions. The main research question of this study is "what are the sustainability dimensions and metrics used in measuring the sustainability of big data systems."

3.1.2. Executing

In the executing phase, key words relevant to this study was used as shown in Table 1. The electronic databases used to identify the papers were also mentioned below. Seeking synonyms is crucial in this phase as it expands the possibilities for the researcher to obtain more relevant journal articles from databases.

Table 1. Databases and search strings

Databases	Search strings
Scopus, IEEE Explore, Science Direct, Emerald, Google Scholar	"Big Data Systems" "Big Data **and** Sustainability," "Sustainability **and** big data systems," "Big Data system **and** Energy efficiency," "Big data systems **and** Resource efficiency," "Sustainability dimensions," "Software sustainability measurement," "Energy and Resource Efficiency," "Energy and Resource Efficiency **or** Big data systems," "Energy consumption **and** big data systems," "Resource consumption **and** big data systems."

On top of that, the executing stage entails the consideration of inclusion and exclusion criteria in selecting quality papers. The papers will be chosen to read only if they satisfy the criteria. The inclusion and exclusion criteria for this study are detailed in Table 2.

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timeline	2005-2023	<2005
Document type	Published journals, articles, and proceedings	Chapters in a book, unpublished papers, irrelevant scope, and non-cited papers
Language	English	Non-English

The search process in the databases results in 119 journal articles that are relevant to the search strings. Then, certain duplicated and non-relevant papers were removed in this stage upon reading the abstracts of the papers. Thus, the remaining papers that were chosen to read were only 14 papers which is only about 12 % of the total papers abstracted. Despite this, a quality assessment is an essential to confirm if the abstracted papers meet the quality benchmarks. According to the guideline in [44], the quality assessment criteria have four questions (Q1-Q4) as tabularized in Table 3. The results of the quality assessment are discussed in the reporting stage.

Table 3. Quality assessment criteria

No	Item	Answer
Q1	Is there a clear description of the aims and objectives of the investigation?	Yes/no
Q2	Is the paper explained the method of analysis pertinent and adequately?	Yes/no/partially
Q3	Is the paper supported by primary data?	Yes/no
Q4	Is the paper explained the model structure in detail?	Yes/no/partially

3.1.3. Reporting

The 14 papers chosen has been validated as a good and very good quality papers as it has met the benchmarks suggested by Okoli [44]. The summary of the quality assessment of the 14 papers are detailed in Table 4. The quality of papers would be considered as very good and good if its total score achieved the range of (3-4) and (2-3) respectively. Table 5 presents the results of the quality assessment.

Table 4. The summary of the quality assessment

Ref.	ID	Q1	Q2	Q3	Q4	Total
[34]	A4	1	1	1	1	3
[35]	A6	1	1	1	1	3.5
[36]	A1	1	1	1	1	3
[37]	A10	1	0	1	1	2
[38]	A11	1	1	1	1	3.5
[39]	A12	1	1	1	1	4
[40]	A3	1	0.5	1	1	2.5
[41]	A2	1	0	1	1	2
[42]	A13	1	0.5	1	1	3
[43]	A14	1	1	1	1	4
[47]	A9	1	1	1	1	4
[48]	A7	1	1	1	1	4
[49]	A5	1	1	1	1	3
[50]	A8	1	1	1	1	4

Based on the results shown in Table 5, 11 papers which is 78.5% are considered as very good. The remaining 3 papers which is about 21.5 % are good quality papers. Since, none of the papers falls in the category of poor and very poor, all these 14 papers are accepted to be referred as this study's literature work.

Table 5. The results of the quality assessment

Quality scale	Very poor (<1)	Poor (1-<2)	Good (2-<3)	Very good (3-4)	Total
Number of studies	0	0	3	11	14
Percentage (%)	0	0	21.5	78.5	100

The following step is to present the analysis on the five sustainability dimensions which illustrated in the Table 6. The analysis shows that Environmental holds the highest frequency which is 12 and the second highest is the economic which is 11. The remaining dimensions which are social, technical, and individual has the values of 10, 9, and 8 respectively.

Table 6. The analysis of sustainability dimensions

Ref.	Technical	Environmental	Economic	Social	Individual
[34]	/	/	/	/	/
[35]	/	/	/	/	/
[36]	/	/	/	/	/
[37]		/	/	/	
[38]		/	/	/	
[39]	/				
[40]	/	/	/	/	/
[41]	/	/	/		/
[42]		/	/	/	/
[43]		/			
[47]	/		/	/	
[48]	/	/			/
[49]	/	/	/	/	/
[50]		/	/	/	
Total	9	12	11	10	8

Furthermore, there are two categories of papers namely conceptual and empirical. This study found 9 conceptual and 5 empirical papers. The number of both type of papers and the years of its publication are as presented in Figure 1. The conceptual paper ranges from the year 2008 till 2020 meanwhile empirical paper ranges from 2016 till 2022.

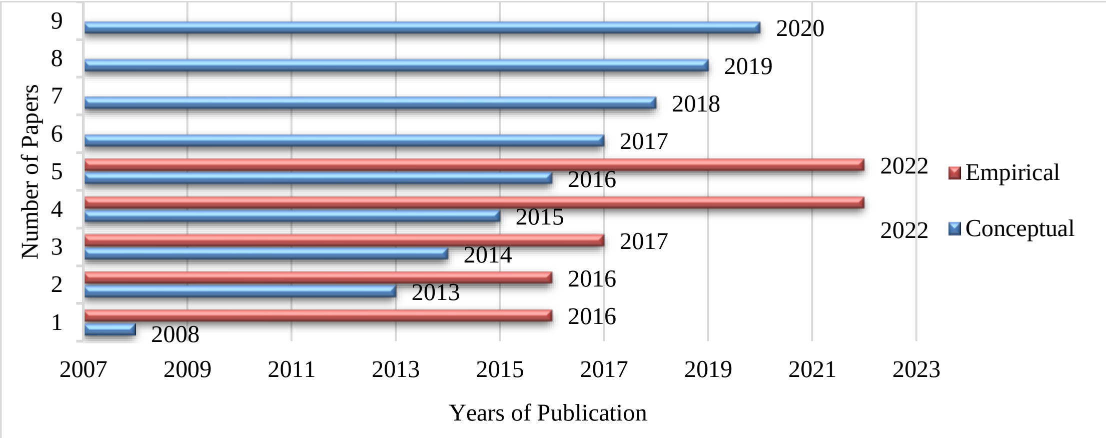

Figure 1. Category of paper according to publication year

3.2. Instrument development

The next step after deriving the metrics based on through literature is the instrument development. This study employs quantitative research method and the instrument would be used is a questionnaire. A questionnaire was developed with a five-point Likert scale ranging from 1'strongly disagree' to 5'strongly agree'. The questionnaire consists of the five sustainability dimensions and its 29 metrics. Each metrics has one question.

3.3. Expert review

The developed questionnaire will then be sent to the expert's validation. The purpose of the expert review is to validate the questionnaire and the proposed metrics. The feedback and suggestions of experts for improvement are crucial, as they will underscore the relevance and significance of each question in the questionnaire. Modifications to the questionnaire and proposed model would be made if there were any comments from the experts. Thus, experts with prior knowledge and a minimum of five years of experience in the big data field have been selected to validate the questionnaire and proposed metrics. The selection criteria and number of experts were adopted according to focus group research in [51]. Then, the five experts were approached through LinkedIn and email. The expert review session was conducted separately by fixing an appointment based on their availability. The profile of the experts is demonstrated in Table 7.

Table 7. Expert's profile

Expert no	Position	Area of expertise	Highest qualification	Type of organization	Years of experience
1	Professor	Big data, system development and enterprise database management system	Ph.D.	Public	24
2	Associate Professor	Big data and databases including analytics, data management and mobile computing	Ph.D.	Public	13
3	Associate Professor and Senior Data Scientist	Big data, machine learning, Python and data engineering	Ph.D.	Private	19
4	Analytics Leader	Big data, artificial intelligence, machine learning, and internet of things	Master's Degree	Private	25
5	Senior Data Science Engineer	Big data, backend developer and data science	Bachelor Degree	Private	5

4. PROPOSED SOLUTION

To enhance the sustainability of big data systems, this study proposes five sustainability dimensions. The significance of each dimension has been elaborated on in this section. Also, the derived metrics for each dimension are stated here.

4.1. Technical

The importance of technical has been highlighted in [34], [35], [47]. Technical play's significant role in contributing to sustainability [47]. Technical is defined as the "ability of the system to be long-lasting with changes in system function" [48]. It should be created for long-term usage, easy to adapt by the users, and should be maintainable and modifiable according to future needs [34], [35], [49]. Technical would be measured using 8 sub-metrics such as perdurability, maintainability and several more. It is evident that technical is one of the important dimensions that has been used to improve the sustainability of software processes and products. Thus, technical is believed to be one of the potential dimensions to measure the sustainability of big data systems.

4.2. Environmental

Environmental is the dimension that has been given importance in a vast when compared to the other four sustainability dimensions. Environmental focuses on the resources used should be eco-friendly and minimized [35], [48]. It is defined as the need to protect natural resources including air, water, minerals, land, and ecosystem services which may bring betterment in human welfare [34], [49]. Meanwhile, environmentally friendly software is referred to as green software [34]. This dimension has five metrics but three metrics which are reusability, modifiability, and availability are extensively used in most studies. These metrics are significantly considered in [48] as they reduce negative impact on the environment by increasing the sustainability of software processes and products. Therefore, the environmental aspect is highly prioritized in this study to measure the sustainability of big data systems.

4.3. Economic

The major focus of economics is to maintain capital and added values which are also called as assets [34], [49]. A forecast of the economy is crucial to avoid any investment risk for the stakeholders. The importance of economy in the context of green was studied in [27], [34], [35], [49], [52]. The most important and used sub-metric in the economy is long-term profitability where the investment in a particular product or process should be risk-free or able to provide a high return on the investment without loss [34], [49], [53]. Another important metric is cost reduction. For an instance, the server used for the purpose of data storage is expensive [10] and there is an immediate need for an appropriate solution. As the big data system is an asset developed for long-term use, this study considers economic as an important dimension in measuring the sustainability of big data systems.

4.4. Social

Social is defined as the protection of the interests of social communities such as groups of people or organizations [42], [48]. This dimension focuses on preserving the social capital and the unity of a specific community [34], [49]. There are two sub-metrics considered under social dimensions which are accessibility and knowledge sharing. Accessibility is the metric that has been used to measure the sustainability of the software engineering process by [35], [48]. Meanwhile, knowledge sharing was emphasized as they are important part to be considered while working in a team [20], [48]. Hence, social was selected to measure the sustainability of big data systems.

4.5. Individual

Individual focuses on the maintainability of various aspects such as health, education, skills, and the level of satisfaction when the focus turns to the job [34], [35], [48], [52]. Individual focuses on the positive impacts and benefits that should be obtained by an individual and this study categorizes an individual as an employee. This dimension is unique because it prioritizes the role and job satisfaction of an employee [34], [42], [48], [52]. For an example, this dimension is used in measuring the job satisfaction of an employee by evaluating some important sub-metrics as mentioned above. This dimension also covers the aspects of fulfillment, rights to act in the environment, and human dignity [41], [54]. As the data analyzing task is considered a difficult and stressful job, it is crucial to have this dimension in measuring the sustainability of big data systems.

5. DISCUSSION

Interpretation of the results obtained in this study will be discussed in this section. The main research question of this study is "what are the sustainability dimensions and metrics used in enhancing the sustainability of big data systems." This study selected 29 metrics and categorized them into their dimensions based on the literature review as shown in Table 8.

5.1. Metrics of sustainability dimension

The bulk of the literature primarily addresses extensive data handling and the security and privacy issues of big data systems. Building upon these insights, this study seizes the opportunity to propose five sustainability dimensions by adding technical and individual while the prevalent sustainability dimensions addressed in most literature are environmental, economic, and social. Empirically, these dimensions shown positive relationships in measuring green software products [50] and processes [35]. Both studies have collected data through surveys to demonstrate these positive impacts. In addition to the studies mentioned, technical, individual/people, and environmental dimensions shows significant positive results in measuring the greenness in software processes through qualitative study [48]. Unlike these studies, which relied on interviews for validation, this research adopts a quantitative approach to validate the dimensions and metrics suitability for big data systems. Similarly, social dimension is positively related to developing green software products and the contributing factors are tool support and employee support [20], which are diametrically dissimilar from the metrics included in this study's social dimension that are accessibility and knowledge sharing.

This research has addressed numerous gaps in the existing literature. The importance of technical sustainability in developing high-quality software has been emphasized and confirmed the effectiveness of their proposed solution with a qualitative approach [39], but this study stressed technical sustainability alongside other four significant dimensions in measuring the sustainability of big data systems using quantitative method. In addition, huge attention has been paid to a technical factor called maintainability in [40], but this study broadens the scope by including various attributes of technical sustainability, thereby providing a more robust contribution to the literature. In the realm of individual sustainability, prior work has emphasized the well-being of software engineers [42], nonetheless, this study offers a more comprehensive view of individual sustainability by expanding focus on factors like motivation, knowledge, and rewards for professionals working in the field of big data. Despite this, human behaviour has been a focal point in environmental sustainability [43], but this research prioritized the system's characteristics like flexibility, modifiability, and time behaviour to effectively measure its environmental sustainability.

Table 8. Metrics of sustainability dimensions

Dimension	Metrics	References
Technical	Maintainability	[23], [27], [34], [47], [52], [55]-[57]
	Predictability	[38], [55], [58], [59]
	Dependability	[38], [59]-[61]
	Fault tolerance	[10], [15], [16], [23], [26], [62]
	Perdurability	[23], [34], [49], [63]
	Understandability	[57], [64], [65]
	Throughput	[5], [16], [17], [20], [64], [66]
	Modularity	[7], [23], [32], [52], [56], [63]
Environmental	Reusability	[16], [22], [23], [38], [39], [47], [52], [55]
	Flexibility	[20], [27], [47], [48], [64]
	Modifiability	[17], [23], [27], [39], [47], [48], [52], [56], [59], [67]
	Time behavior	[27], [32], [27]
	Availability	[7], [10], [16], [17], [23], [27], [47], [64]
Economic	Long-term profitable	[34], [49], [52], [63]
	Cost reduction	[20], [34], [48]
	Return of investment	[42], [49], [55], [68], [69]
	Replaceability	[23], [27], [47], [56]
	Capacity	[5], [27], [47], [63], [64]
	Income	[34], [49], [52], [55], [64], [70]
Social	Accessibility	[27], [34], [38], [47], [71]
	Knowledge sharing	[20], [38], [42], [48]
Individual	Motivation	[55], [72], [73]
	Working environment	[34], [48], [55], [59], [74]
	Knowledge/skills	[34], [48], [49], [55], [64], [68], [75]-[77]
	Working hours	[34], [59], [77]
	Rewards/appraisal	[24], [48], [78], [79]
	Learnability	[10], [20], [76], [80]
	Communication skills	[55], [64], [68], [79]
	Health	[20], [48], [63]

A closely related prior study intended to identify the green metrics for big data systems but they are general software metrics solely focused on energy optimization [17] while this study addresses the specific metrics and validates them with five experts in the field. Nevertheless, there were only three dimensions; environmental, economic, and social introduced by [37], [3] to the IS framework but this study added and proposed two more dimensions which are technical and individual. This research thus makes a prominent and original contribution to the field, extending previous findings to address the complex sustainability challenges of big data systems.

5.2. Expert's feedback

The first expert confirms all the metrics are appropriate except knowledge sharing in the social dimension. Knowledge sharing was advised to remove as it is not relevant in measuring the sustainability of big data systems. The second expert also agrees with all the metrics. Yet, privacy and security have been emphasized as it is very important metrics for big data systems. So, privacy and security are the metric that has been added upon the expert's suggestion as it is one of the social responsibilities that is compulsory to be included in the field of technology. Literature also supports privacy and security to be part of social sustainability [47]. In addition, this expert advised to have at least 2 questions for security and privacy each. Then, another question was suggested to add for fault tolerance in the technical dimension as it is one of the major parts of big data systems. Next, the third expert agreed with all the metrics and commented the questionnaires are well-structured and easy to understand. Similarly, the fourth and fifth experts were also satisfied with the questionnaire and questions as the metrics are suitable for measuring the sustainability of big data systems. All the experts have validated the proposed model and there is no modification needed. In summary, the first and second experts' advice was accepted and made the necessary modifications to the questionnaire. Thus, knowledge sharing was removed while privacy and security were added with 2 questions each. Then, the modified questionnaire was agreed upon by the last three experts. The modified questionnaire consists of 33 questions. The finalized metrics in each dimension are presented in Figure 2.

TECHNICAL	ENVIRONMENTAL	ECONOMIC	SOCIAL	INDIVIDUAL
• Maintainability	• Reusability	• Long-term profitable	• Accessibility	• Motivation
• Predictability	• Flexibility	• Cost reduction	• Privacy	• Working environment
• Dependability	• Modifiability	• Return of Investment (ROI)	• Security	• Knowledge/ skills
• Fault Tolerance	• Time behavior	• Replaceability		• Working hours
• Perdurability	• Availability	• Capacity		• Rewards / Appraisal
• Understandability		• Income		• Learnability
• Throughput				• Communication skills
• Modularity				• Health

Figure 2. The revised metrics

6. CONCLUSION

A systematic literature has been conducted and five sustainability dimensions have been proposed to tackle the sustainability challenges in big data systems. A total of 29 metrics were derived initially and categorized into these dimensions. Then, a questionnaire was developed for experts' validation and there were changes made to the questionnaire as advised by the experts. The refined questionnaire consists of 33 questions with 30 metrics. This modified questionnaire is now ready for distribution to the respondents in the big data field for a pilot study. The results of the pilot study will be analyzed using the Rasch measurement model.

The proposed sustainability dimensions and metrics serve as a valuable guide for organizations and policymakers to comprehend and address the underlying issues in big data systems. In addition, the proposed solution can be employed as a benchmarking tool in organizations to evaluate the sustainability of their big data systems. Despite the benefits, this study has certain limitations. While the identified dimensions and metrics offer a solid theoretical foundation, their practical applicability and effectiveness remain untested until the pilot study is completed. Besides, this study relied on expert's validation without extensive field testing, future research should focus on real-world application and iterative refinement of these metrics to enhance their practical relevance and effectiveness. This will allow the organizations to implement and practice sustainability more effectively. The implications of this study are vital for both academics and practitioners where they could build strong foundational work to explore new dimensions of sustainability in big data, while practitioners may utilize these metrics to enhance the sustainability of their systems.

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