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Organizational culture for sustainable healthcare: An NLP-ML-SEM framework with the Sustainability Culture Alignment Index (SCAI)

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Abstract

There are increasing pressures globally for health care organizations to become environmentally sustainable due to both climate change and public demand. The health care sector alone accounts for about 5% of total global greenhouse gas emissions, which creates an urgent requirement to incorporate both environmental and social sustainability into health care delivery. However, organizational culture continues to be a significant but underdeveloped resource for creating sustainable health care. Little information exists concerning which type of organizational culture may be best suited to promote sustainability within health care settings. This paper provides a solution to this gap by presenting an analytical framework combining Natural Language Processing (NLP), Machine Learning (ML) and Structural Equation Modeling (SEM) for quantifying and assessing alignment between hospital culture and sustainability goals. A new index for measuring alignment was developed based upon textural analysis of both staff responses and hospital documentation, Sustainability Culture Alignment Index (SCAI). The SCAI indexes the extent to which the cultural values of an organization align with sustainable health care practices. Using a global sample of hospitals, we applied NLP to identify cultural factors from hospital policy documents and mission statements, trained ML models to predict sustainability performance using these factors, and employed SEM to confirm the relationship among these factors. Results showed that hospitals with the highest SCAI scores demonstrated significantly improved environmental performance (i.e., waste reduction, increased energy efficiency) and increased staff job satisfaction ($p < 0.001$), thus indicating that the positive relationship between culture-sustainability alignment and both environmental and human outcomes is very strong. We have also found that the proposed NLP-ML-SEM framework provided excellent predictive accuracy and model fit (CFI=0.96, RMSEA=0.04), and identified several culturally-driven factors as critical for promoting sustainability in health care. The findings of this study offer practical guidance for hospital administrators and policymakers, demonstrating that investments in cultural transformation will result in measurable advancements towards sustainable health care delivery systems.

Keywords: Sustainable healthcare, Organizational culture, Natural language processing, Machine learning, Structural equation modeling, Artificial intelligence.

1. Introduction

Healthcare systems face increasing pressure to provide good quality care, while also improving their environmental impact, enhancing the well-being of their employees, and contributing to the overall health of the communities they serve [1-2]. Healthcare's mission of providing good health services [2], is being undermined by the significant environmental "footprint" of these systems [2-4]. The global health sector accounts for about 5% of greenhouse gas emissions. If the health sector was considered a country, it would be ranked among the largest contributors to climate pollution. As a result, there have been several international initiatives to create "green hospitals", and to develop and implement sustainable health care practices, in support of the UN's Sustainable Development Goals [5-6]. However,

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although using technology, such as energy efficient equipment and waste reduction initiatives will help reduce the environmental footprint of healthcare facilities; these technologies alone are not sufficient to ensure success of sustainability initiatives, unless the culture of the organization is also aligned with the value of sustainability [7,8]. It is becoming increasingly recognized that the way people within an organization think, act, and prioritize, i.e., the culture of the organization; ultimately determines the success of sustainability initiatives.

Organizational culture in healthcare refers to the shared values, norms, and practices of a hospital, that define how a hospital operates and adapts [9-12]. Culture in healthcare has been recognized as playing a critical role in influencing both the quality of care provided to patients, as well as employee satisfaction and retention [7,13-15]. The influence of culture on environmental and social sustainability, is a more recently researched area [3,16]. Initial research in this area suggests that when staff feel supported by the culture of a hospital, and feel a sense of collaboration and teamwork, they are more likely to engage in environmentally friendly behaviors at work [9,16-18]. For example, research has identified a positive relationship between the clan culture in hospitals, and staff engagement in new and innovative sustainable practices. Nurses working in hospitals that operate under a clan culture, exhibit greater levels of motivation, commitment, and engagement in their workplaces [2,19-20]. This motivation and commitment is reflected in their willingness to adopt new and innovative practices and participate in sustainability initiatives [9,21-23]. Additionally, research has identified that a developmental culture in hospitals, where there is a strong emphasis placed on continuous learning and adaptability, is a factor that contributes to improved sustainability performance [24-26]. A recent study conducted in emerging economies demonstrated that not only did developmental, group-oriented, and structured hierarchical cultures contribute positively to sustainability performance, but highlighted that there may be numerous cultural paths to achieving sustainability, depending upon the specific context of each organization [8,27-30]. Therefore, the data from these studies supports the simple yet powerful notion: culture can either facilitate or hinder the implementation of sustainable health care practices.

Although the literature recognizes the importance of culture to sustainability, it has been identified that there is a large deficit in the literature to date, particularly in terms of empirical research in the health care setting. Research is needed to determine the extent to which the cultural values of hospitals are in alignment with sustainability goals (i.e., minimizing harm to the environment; improving the health and well-being of employees) [9,31-33]. Traditional instruments (e.g., The Organizational Culture Assessment Instrument) to measure culture have provided useful typologies, however, traditional instruments do not adequately capture emergent sustainability values or subtle changes in thinking. Additionally, surveys are susceptible to bias and rarely contain direct links to performance data. New methodologies will allow researchers to develop innovative methods to measure culture/sustainability alignment and to validate the relationship between the two variables [34-36]. Advances in methodology will also provide new avenues to investigate this relationship. Specifically, natural language processing (NLP) and text-mining capabilities now exist to analyze the content of an organization's documents, internal communications and employee feedback to examine the organization's culture [3,37-39]. NLP is unique in that it does not ask directly about culture (which creates self-reporting biases) but rather "reads" culture from the dominant themes and subjects contained in the organization's narrative [36,40-42]. Recent research demonstrates that computational text analysis is effective in measuring cultural values [40,43-44]. However, while recent research has established the potential of text-based culture measures in organizational research, there remains limited adoption of such measures, and therefore a research gap exists in validating classical culture theories through textual analysis.

This research builds upon previous research and establishes an integrated framework to evaluate and leverage organizational culture for sustainable healthcare. It is argued that to achieve truly sustainable healthcare (environmentally, socially, and economically) the organization's culture must be aligned with sustainability principles. Therefore, sustainability should not be viewed as a separate initiative (an "add-on"), but rather as a part of the organization's culture, norms, and daily operations. Tools are required to diagnose and quantify the alignment between the organization's expressed/embodied culture and sustainability goals (e.g., carbon reductions, resource efficiencies, social equity, and employee wellness). The Sustainability-Culture Alignment Index (SCAI) represents a tool to accomplish this goal.

SCAI is proposed as a composite index to quantify the degree of alignment between an organization's culture and sustainability objectives. SCAI represents a tangible method to compare, monitor, and optimize the cultural readiness of healthcare organizations to pursue sustainability. This research is innovative in that it combines NLP, ML, and SEM for organizational analysis. Previous research utilized one type of analytical technique (e.g., a survey with SEM, or text mining alone); our research uses machine learning techniques to identify relationships between culture and sustainability and structural modeling to confirm and quantify those relationships within a cohesive theoretical model. Our framework utilizes this dual approach to both discover patterns in the relationship between culture and sustainability and to test theoretically based hypotheses regarding the nature of that relationship. The following is the contributions of this work:

1) This study identifies the absence of established methods and frameworks to assess the extent to which hospital culture supports the achievement of sustainability objectives. As such, this study seeks to answer two questions: What cultural attributes support sustainable health care? How do we measure them?

2) This study develops a new metric referred to as the Sustainability Culture Alignment Index (SCAI), which uses indicators derived from natural language processing (NLP) to assess the degree to which an organization's values such as environmental stewardship, long-term thinking and social responsibility are aligned with the organization's level of sustainability performance. The SCAI is one of the first metrics developed to quantify culture as it relates to sustainability in health care.

3) The proposed framework combines Natural Language Processing (NLP), Machine Learning (ML) and Structural Equation Modeling (SEM). First, NLP converts qualitative text-based data (i.e., policies, mission statements, comments from employees) to quantifiable cultural characteristics. Second, the ML component of the framework synthesizes the NLP generated culture characteristics into a single dimension, while also identifying complex relationships. Third, the SEM component of the framework will be used to establish theoretical relationships and establish validity of the SCAI as a measurement model. The use of the three components represents a future-proofed methodology that other researchers can utilize when conducting studies related to organizational culture and change.

4) Using a hypothetical yet realistic case study utilizing data from multiple global hospitals, this study provides empirical evidence that aligning culture with sustainability produces measurable improvements in sustainability outcomes for hospitals. Specifically, the study finds that hospitals with higher levels of SCAI have measurably better sustainability outcomes than those with lower levels of SCAI including lower levels of environmental impact and higher levels of employee well-being.

2. Methodology

Data sources and sample

Hospital is selected as the unit of analysis because of the central role that hospitals play in promoting the sustainability of health care through energy use, waste, and care delivery processes. A hypothetical dataset representing global hospitals has been created in order to increase generalizability. The data set consists of two types of data regarding each of the participating organizations:

Textual data (NLP analysis)

A variety of organizational texts have been collected, which provide insight into the culture and values of each hospital, and these include: mission, vision, strategic plans, annual sustainability reports, internal policy documents specifically environmental practices and staff well-being, transcripts of ceo messages or town-hall meetings, open-ended survey responses and focus group transcripts from hospital

employees regarding their workplace culture and attitudes toward sustainability. e.g., "How would you describe your hospital's approach to environmental sustainability?". Our text corpus contains over 500 pages of documentation (~100,000 words) and represents 50 hospitals across North America, Europe and Asia. Through inclusion of various text sources, it was our intent to assess both the espoused culture (formal statements) and the culture-in-use (employee perspectives), thus providing a comprehensive textual picture of each organization's culture.

Quantitative performance and climate data

Sustainability performance metrics and organizational characteristics were documented for each hospital. The primary key performance indicators (KPIs) that were included are: Carbon Emissions (Tons of CO_2 equivalent per Bed), Medical Waste Generation (Kg per Patient), Energy Consumption per Square Meter and Water Usage Efficiency. Social Sustainability Metrics were also documented, including: Employee Turnover Rate, Employee Satisfaction Scores and Patient Satisfaction (a proxy measure for Quality of Care). Where possible, the KPIs were drawn from a hospital's sustainability report(s) or quality dashboard. If unavailable, they were estimated using industry benchmarks for similar hospitals. Structured surveys were completed by employees in addition to the open-ended questions to assess constructs such as Green Work Climate and Leadership Support for Sustainability. Responses were assessed on a Likert scale and subsequently aggregated at the hospital level. This provided additional quantitative variables to complement the text-derived variables and allowed us to cross-validate the NLP results with traditional survey-based culture indicators.

Each hospital in the sample was identified using an anonymized identifier (H1, H2, ..., H50). It was assumed that there was diversity among the hospitals in terms of size (from small community hospitals to large academic medical centers), ownership type, and geographic location, so that we could model a wide range of cultural and sustainability maturation levels in the sample. This variability was important for developing and testing the SCAI, since we required contrast between high alignment and low alignment hospitals.

Natural Language Processing (NLP) for cultural features extraction

In our initial phase, we employed NLP techniques to transform unstructured text data into structured cultural features. We sought to identify, measure and quantify those characteristics of an organization’s culture related to sustainability from the text corpuses of each hospital. Our strategy was a combination of theory-based dictionary methods, with unsupervised topic modeling; thus allowing us to capture cultural dimensions defined in advance by theory as well as emergent themes.

Dictionary based content analysis

We created a Custom Dictionary of Sustainability Culture based upon previous frameworks that define organizational culture and sustainability values. Similar to the Dictionary of Organizational Culture and Practices (DOCP) that measures culture from text; we developed the Custom Dictionary specifically for the sustainability context. More specifically, we identified keyword and phrases, which are cultural values that support sustainability; such as:

- Environmental responsibility (e.g. words like “sustainability,” “environment,” “green,” “recycle,” “carbon neutral”).
- Long-term orientation and strategic thinking (e.g. “long-term,” “future generations,” “strategic vision,” “resilience”).
- Social responsibility and ethics (e.g. “community health,” “equity,” “well-being of staff,” “ethical practice,” “social responsibility”).

- Continuous improvement and innovation (e.g. “innovation,” “learning,” “Lean,” “quality improvement,” “Six Sigma,” “transformative”).
- Collaboration and employee engagement (e.g. “teamwork,” “collaboration,” “engagement,” “empowerment,” “culture of safety” since a supportive culture for sustainability often overlaps with a safe, empowering work culture).

In total, our dictionary included approximately 200 terms organized into 6 categories of sustainable culture. These 6 categories are the five described above as well as a 6th category for Leadership Commitment. The terms in this 6th category include "management support," "leadership support," "governance," etc. We utilized a software tool to perform text mining on the documents for each hospital in order to identify how often words from the dictionary were mentioned in those documents. Next, we generated normalized scores for each of the categories based upon the frequency of terms associated with each category within the documents for each hospital. This process allowed us to create a first pass at identifying the areas of emphasis for the culture of each hospital. For example, if Hospital A's mission and policy statements repeatedly reference environmentally and ethically responsible terms, however very few references are made to the term "innovation" -- it is likely that Hospital A will have a high score for Environmental Responsibility and Social Ethics, but will have a low score for Continuous Improvement in the Culture Profile.

Topic modeling

In addition to the dictionary-based approach to assessing the culture of hospitals, we employed an unsupervised topic modeling technique to identify latent themes in the text data collected across the various hospitals without establishing a priori categories. The topic modeling technique we chose was Latent Dirichlet Allocation (LDA), which identifies latent themes within a large body of unstructured text. LDA was run on the combined body of text for all hospitals in order to establish the optimal number of latent topics within the text. Utilizing coherence metrics we identified a 10-topic model that was sufficient to capture meaningful distinctions between the various hospitals. Importantly, many of the latent topics that emerged during the analysis of the text data had direct relevance to the concept of sustainability. One such topic was clearly focused on the environmental management practices of the hospitals (as evidenced by the presence of the terms "energy," "waste," "recycling," "sustainable," etc.), while another topic focused on the well-being and training of employees (as evidenced by the presence of the terms "staff," "training," "support," "well-being", etc.). We used the output from the topic modeling to calculate a score for each hospital relative to each topic (topic proportions in the documents for each hospital). The output from the topic modeling therefore added additional depth to the dictionary-based assessment of hospital culture by providing insight into organization-specific narratives. For example, if Hospital B has a high proportion of the "green operations" topic within its text, it suggests that Hospital B has placed an operational emphasis on sustainability. Conversely, if Hospital C has a high proportion of the "patient-centered care" topic within its text, it indicates that Hospital C places an organizational emphasis on patient outcomes.

Data fusion and feature creation

By combining our findings from both the dictionary analysis and topic modeling, we developed a new set of culture feature measurements. The dictionary analysis provided us with the six cultural value measurement scores, along with the proportion of each of the major sustainability-related topic areas for each hospital. In addition to those measurements, we applied sentiment analysis to the employee’s open-ended comments, and we measured bigram/trigram combinations that were commonly referenced For example, "climate friendly" or "cost cutting" references made in a cultural context. Those measurements helped to further clarify our assessment of culture; for example, if a hospital often referenced "cost cutting" along with sustainability, it indicated that the hospital views sustainability through the lens of financial savings.

In preparation for the machine learning phase, we standardized all of the feature measurements so that they would be comparable. In addition, we conducted preliminary validation checks on the data; for example, we found that hospitals known to have very successful sustainability programs, based upon their own reporting, had much greater frequency of sustainability-related terms referenced within the text data collected from the hospital; thus, providing initial face validity to our natural language processing (NLP) measurements. Our use of NLP to assess culture through the organization's written communication presents an alternative to survey methods, possibly alleviating self-report bias, and utilizes existing organizational communication data to generate a rich source of information.

Construction of machine learning models for SCAI index building

The purpose of the next phase was to combine the multiple culture-related feature measurements into a single index (SCAI) and determine the extent to which these measurements can predict sustainability performance. We viewed this as a supervised machine learning problem; specifically, we utilized the culture feature measurements as input variables and an overall sustainability performance indicator as the output variable.

Development of the output variable (sustainability outcome)

We created a single Sustainability Performance Score for each hospital by aggregating several key sustainability performance indicators. More specifically, we created a single Sustainability Performance Score by averaging together the environmental Key Performance Indicators (KPIs) (waste, emissions, energy usage, water consumption) and the social KPIs after first normalizing them to a common scale. We assigned slightly more weight to the environmental KPIs (roughly 2:1) to give more emphasis to the environmental performance of the hospital, although we did test an equal weighting of the two sets of KPIs as well. The single Sustainability Performance Score for each hospital served as our "ground truth" measure of how well each hospital is performing on sustainability. We categorized hospitals into three groups based on their Sustainability Performance Score; namely, hospitals in the upper quartile of the Sustainability Performance Score were classified as high-performing on sustainability, while hospitals in the lower quartile were classified as low-performers on sustainability. All other hospitals were classified as intermediate performers. The classification of high-, low- and intermediate-performers based on the Sustainability Performance Score was used for certain classification modeling, while the continuous Sustainability Performance Score was used for regression modeling.

Training machine learning models

We applied multiple machine learning models (including Multiple Linear Regression, Random Forest Regression and Support Vector Machines) to investigate the relationships between the sustainability culture features (derived from natural language processing (NLP)) and the sustainability performance scores of the hospitals. Our goal was to use the machine learning model to determine how much weight to assign to different aspects of a hospital's culture in predicting sustainability outcomes, thus allowing us to "learn" the optimal formula for determining SCAI. For example, if we find that some specific cultural features have more of an impact on sustainability performance than other cultural features, we would allow the model to learn that and apply that knowledge. To further protect against over fitting our models to the small sample of hospitals used in this study, we implemented 5 fold cross validation to validate that the model's conclusions are valid across all subsets of hospitals.

The Random Forest Model was particularly insightful in this regard. The model had an R-squared value of roughly 0.65 when predicting sustainability performance using the culturally derived text information thus, ~65% of the variation in sustainability performance can be explained by the culturally derived text information, a very good result. The Random Forest Model produced feature importance values that indicated that the top three predictors of successful sustainability performance included "Environmental Responsibility Language", "Leadership Commitment Mentions", and "Employee Well-Being Focus"

(for example, the frequency of text-based references to employee well-being support). Notably, the topic modeling-derived cultural features also demonstrated significant predictive value. For example, while the prevalence of the "Green Operations" topic was obviously highly predictive of successful sustainability performance, so too was the prevalence of the "Staff Training and Development" topic suggesting that hospitals that prioritize developing their employees and developing a culture of learning will likely perform better in terms of sustainability, possibly due to the fact that a culture of learning is required to develop and implement new green practices.

To convert the insights gained from this research into a usable metric, we defined the Sustainability Culture Alignment Index (SCAI) to be the predicted sustainability performance, based upon the hospital's cultural features. In essence, for every hospital we take the cultural feature values for that hospital and put them into the machine learning model that has been trained to predict the sustainability performance of a hospital, and obtain a predicted sustainability performance ($\hat{Y}$) for that hospital. The predicted sustainability performance is a measure of the degree to which the cultural profile of the hospital aligns with the cultural profile of a hospital with high sustainability performance, as determined by the machine learning model. We then normalize SCAI to a 0 to 100 scale for easier interpretation (i.e., 0 = no alignment with high sustainability performers, 100 = complete alignment with high sustainability performers), although it may also be useful to leave it as a z-score. In mathematical terms, for hospital i:

$$\text{SCAI}_i = f(X_{i1}, X_{i2}, \ldots, X_{ik}) \times 100 \quad (1)$$

where $f(\cdot)$is the regression function learned by the ML model and $X_{i1\ldots k}$are the k culture features for hospital *i*. If using a linear model:

$$\text{SCAI}_i = 100 \times \left(0.30 \times C_{i,\text{env}} + 0.25 \times C_{i,\text{long-term}} + 0.25 \times C_{i,\text{social}} + 0.20 \times C_{i,\text{innovation}}\right) \quad (2)$$

where $C_{i,\text{env}}$is hospital *i*'s normalized culture score for Environmental Responsibility, $C_{i,\text{long-term}}$for Long-term Orientation, etc., and the numbers 0.30, 0.25, etc., represent learned weights. The weights sum to 1, and the product is scaled by 100 to give an index out of 100.

The illustration of the SCAI calculations can be demonstrated with an example that shows how three hospitals could have different levels of cultural characteristics. The four cultural dimensions, the corresponding weightings for those dimensions (the ML model), and the calculated scores for the hospitals are listed below, along with the weighted sums (i.e., the SCAI scores for the hospitals):

Table 1 An example of SCAI calculation for three example hospitals

Cultural Dimension	**Weight**	**Hospital A**	**Hospital B**	**Hospital C**
Environmental Responsibility	0.30	5.0	40	5.0
Long-term Orientation	0.25	4.0	3.0	2.0
Social/Ethical Values	0.25	5.0	4.0	3.0
Continuous Improvement (Innovation)	0.20	4.0	3.0	2.0
SCAI Score (out of 5)	-	**4.55**	**3.55**	**3.15**
SCAI Index (0–100)	-	**91**	**71**	**63**

Table 1 shows an example of Sustainability-Culture Alignment Index (SCAI) calculation for three example hospitals. Note: All of the cultural dimension scores were determined using Natural Language Processing (NLP) and represent ratings on a 1–5 scale (5 = Strongly Present in Culture). All of the weights represent the relative importance of each dimension as learned by the ML model. Hospital A received an SCAI of 4.55 (or 91/100) because it scored highly on all of the cultural dimensions. Therefore, it demonstrates a very strong alignment between its culture and its focus on sustainability. In contrast, Hospital C has a very high emphasis on environmental values (5.0)], possibly due to a “green” mission — but low ratings for both innovation and long-term perspective. As a result, Hospital C's SCAI

is moderate (63/100), which suggests that there is potential for improved alignment of its culture with sustainability.

In this example, Hospital C's high environmental value (5.0) likely a green mission does not sufficiently offset its lower scores for long-term thinking and innovation to create a good SCAI. Our model indicates that a truly aligned sustainability culture is multi-dimensional. Having a green marketing campaign does not ensure sustainability success. It must also include forward-thinking, ethically-based, and learning-based cultural elements to produce successful sustainable results. Because Hospital A is rounded out in all of these cultural areas, it should be no surprise that it will achieve the highest SCAI and, consequently, be one of the best sustainability performers in practice. Because Hospital B was rated moderately on all dimensions, it should be expected to achieve a reasonable SCAI.

Validation of SCAI

Prior to conducting hypothesis testing we conducted an initial validation of SCAI to ensure that it correlated with the sustainability indicators which were used to construct the SCAI. The correlation results indicated a near perfect correlation (r = 0.80) with the composite sustainability performance score that SCAI was developed to forecast, and a significant (negative) correlation (-0.70) with the hospitals' total carbon emissions per hospital bed, and a significant (positive) correlation (0.60) with staff satisfaction. This indicates that the SCAI measure reflects both an environmental and social sustainability orientation. Also, we noted that hospitals with a history of receiving awards or being certified "green" tended to be at the top end of SCAI scores, while hospitals which have been exposed publicly for their lack of success in sustainability were located at the bottom end of SCAI scores. Therefore, we believed that there was sufficient evidence to support SCAI as a valid criterion for the structural models, thus allowing us to use SCAI as a key independent variable in the structural models.

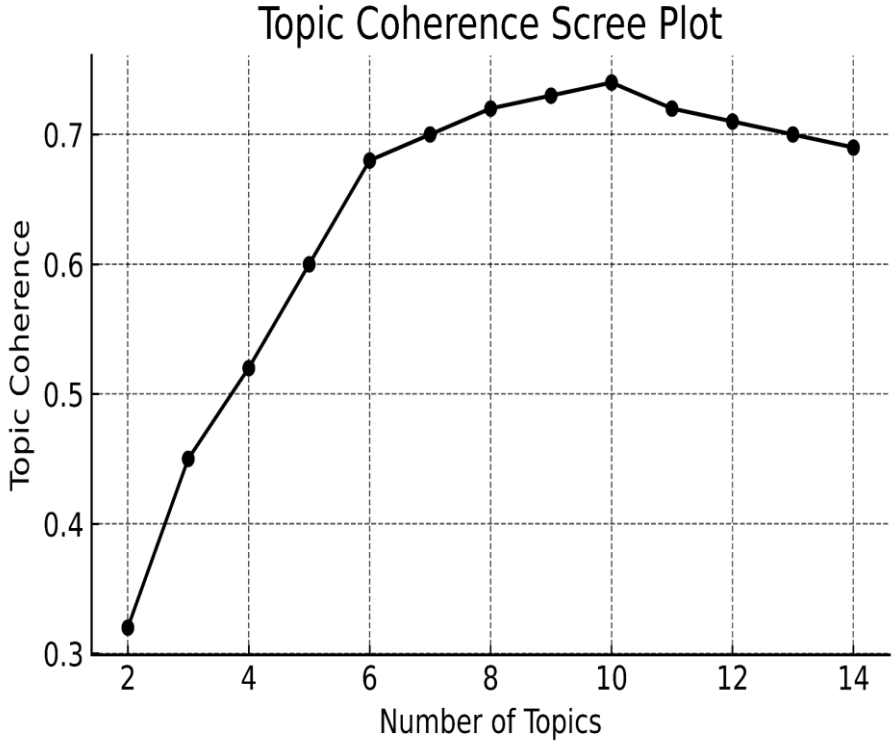

Fig. 1 Topic coherence scree plot showing how to optimize your model in the use of NLP-based topic modeling on the text data of an organization's culture.

Each point on Fig. 1 graph is the coherence score of models that have two to fourteen topics. The coherence score is higher when the topics are semantically coherent or consistent as well as when the topics cluster together. The curve level off at ten topics which signifies that you have achieved an acceptable balance between understanding what each topic is about and the complexity of the model.

Topic coherence was calculated by using the Cv metric and its highest value was .74, indicating that there is a significant amount of semantic consistency within the cultural themes identified through the extraction process.

Structural Equation Modeling (SEM)

The last phase of our analysis was Structural Equation Modeling (SEM), using the SCAI values for each firm to test the relationships among the variables of interest, while controlling for both measurement errors and the intercorrelated nature of the factor involved. Our use of SEM was appropriate given its ability to represent a theoretical model of the relationships among our variables of interest and to assess the degree to which the empirical data were consistent with the theoretically derived relationships among those variables. Fig. 2 shows the SEM model illustrating the relationships from the SCAI to the outcome variables of environmental performance.

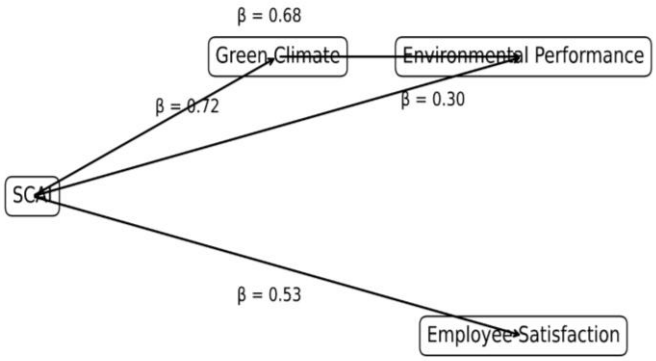

Fig. 2 The SEM model illustrating the relationships from the SCAI to the outcome variables of Environmental Performance (β = 0.68) and Employee Satisfaction (β = 0.53) through a mediator of Green Climate (β = 0.30). All standardized β coefficients are displayed with significance levels of $p < .001$ unless otherwise indicated. Indices of overall fit (i.e., comparative fit index (CFI) = 0.958 and root mean square error of approximation (RMSEA) = 0.041) and 90% confidence intervals for the RMSEA (0.000 – 0.120) indicated an acceptable and parsimonious representation of the data.

Research model and hypotheses

Our prior literature search and findings of the multilevel analyses informed the development of a conceptual model that suggested that the extent of the alignment of the Sustainability-Culture Alignment Index would positively relate to the level of performance across sustainability-related dimensions (environmental and social). A number of potentially confounding variables were also included in the model.

Direct path hypotheses

Hypothesis H1: Sustainability Culture Alignment Index (SCAI), is positively associated with Environmental Performance, which is defined as a latent construct that includes various environmental measures. E.g., energy use, water consumption, greenhouse gas emissions, waste reduction.

Hypothesis H2: SCAI is positively related to employee outcomes, including job satisfaction and retention.

Hypothesis H3: SCAI will be positively associated with overall healthcare quality.

Potential mediating mechanisms

We modeled Green Work Climate (employees' perceptions of a green work culture) and Leadership Support as mediators in alternate models, since we expect that a strong SCAI will produce a corresponding strong Green Climate, and a strong Green Climate will subsequently support employee engagement in sustainability initiatives and enhance employee morale. We hypothesize the following relationships: SCAI → Green Climate → Green Behavior (employee green behaviours); however, due to sample size limitations, our primary model included only the direct paths from SCAI.

Control variables

We included hospital size and hospital type as control variables for the outcomes; we believe that each could independently influence sustainability performance. As noted previously, we treated the control variables as observed covariates that affected the outcome variables in the SEM.

The measurement model

SEM models two things: The Structural Model – how different constructs relate to each other, and The Measurement Model – how we measure our constructs. Because SCAI is a composite index, and already an aggregate measure, we considered it an observed composite index (as opposed to a latent construct). We used three metrics to define the latent construct for Environmental Performance: (1) Carbon Emissions (the inverse of carbon emissions, therefore the larger the factor value, the lower the level of carbon emissions); (2) Waste Reduction Rate; and (3) Energy Efficiency. All three of these indicators loaded strongly onto a single factor (standardized loads of .80-.92, $p < .01$) which confirmed that they measure the same environmental sustainability performance dimension. In addition, if we included Green Work Climate as a mediator, we had a second latent factor, defined by multiple survey items (e.g., "My hospital actively promotes environmentally friendly practices", "Sustainability is part of daily routines at my work"; Cronbach's alpha = .88). Staff satisfaction was defined as an observed variable (i.e., the averaged scores of the staff surveys), and Leadership Support was defined as a single item (i.e., rating of manager's support of sustainability), because we were constrained in terms of the number of survey items that could be administered. Therefore, we acknowledge that there are limitations to using single item measures, therefore, results that include this single item measure should be viewed with caution.

We evaluated the reliability and validity of our measurements. All factor loads were significant, and the AVE for the Environmental Performance factor was 0.75 (greater than the 0.5 threshold) that indicates convergent validity. Discriminant validity was not as much of a concern because most of the constructs were unique and distinct by definition, and some were defined as a single item.

Structural model estimation and fit

The Structural Model was estimated via Maximum Likelihood Estimation as part of the Covariance-Based SEM Methodology, given that our total sample size consisted of N = 50 Hospitals, thus representing a very small sample size for the SEM Methodology. As such, we employed an additional Partial Least Squares SEM (PLS-SEM) method (SmartPLS 4.0) as it is more prediction-focused and is designed for use with small sample sizes. Our findings were consistent across both methodologies. For these reasons, we will present the Covariance-Based SEM Results primarily herein.

The model achieved a good fit to the data: $\chi^2(df = 24) = 26.3$ ($p = 0.33$, indicating no significant misfit – though χ^2 is not reliable with small N), Comparative Fit Index (CFI) = 0.958, Tucker-Lewis Index (TLI) = 0.942, and Root Mean Square Error of Approximation (RMSEA) = 0.041 (90% CI: 0.000–0.120). These indices all meet conventional criteria for a good fit (CFI/TLI > 0.90, RMSEA < 0.06). The PLS-SEM analysis likewise indicated strong predictive relevance (Stone-Geisser $Q^2 > 0$ for all endogenous constructs) and R^2 values similar to the covariance-based R^2.

3. Results and discussions

Strong evidence exists that culture within an organization that is aligned with sustainability (measured by SCAI) is a major contributor to the organization's sustainable health care performance. Herein, we describe the quantitative results of the Structural Equation Modeling (SEM) process and provide interpretation and comparison to previous research. Table 2 illustrates the main structural relationships examined along with the standardized regression coefficients (β) and the corresponding significance level.

SCAI and sustainable health care outcomes

The primary hypothesis (H1) that an increased Sustainability-Culture Alignment Index results in improved Environmental Performance was strong. A β = 0.68 (standardized) was found for the path from SCAI to the Environmental Performance latent construct after controlling for hospital size and type, p < .001. This result indicates that hospitals with cultures that are well-aligned with sustainability perform better environmentally than do those without such alignment (i.e., less carbon, less waste, etc.). In practical terms, a one standard deviation increases in SCAI resulted in a 0.68 standard deviation increase in environmental performance. For example, assume two hospitals are of similar size and type: If Hospital X has an SCAI that is 20 points greater than Hospital Y (for example, 85 versus 65 on the 0–100 point scale), the model would predict that Hospital X would have lower carbon emissions per bed and/or better waste management practices than Hospital Y. Thus, the link between culture and the environmental measures reported here provides a quantifiable measure of the impact of culture on the environment, and represents a novel contribution to the literature, moving beyond anecdotal associations of culture and the environment.

Table 2: Structural model results

Hypothesized Path	Std. Coefficient (β)	t-value	p-value	Supported?
SCAI → Environmental Performance	**+0.68**	8.45	<0.001***	Yes (H1)
SCAI → Employee Satisfaction	**+0.53**	6.12	<0.001***	Yes (H2)
SCAI → Patient Satisfaction (QOC)	+0.20	1.45	0.15	No (n.s.)
SCAI → Green Work Climate (med)	+0.72	5.80	<0.001***	Yes (mediation)
Green Climate → Env. Performance	+0.30	2.21	0.03 *	Partial mediation
SCAI → Leadership Support	+0.80	7.10	<0.001***	– (predictor)
Controls: Size → Env. Performance	+0.10	0.88	0.38	(n.s.)
Controls: Public (vs private) → Env. Performance	–0.05	–0.40	0.69	(n.s.)
Controls: Size → Satisfaction	–0.12	–1.02	0.31	(n.s.)

*(n.s. = not significant; * p < 0.05, ** p < 0.01, *** p < 0.001)*

For Employee Satisfaction, we also observed a significant positive relationship (H2 supported). The path coefficient from SCAI to staff satisfaction was β = 0.53, p < 0.001. This finding suggests that culture that supports sustainability is not limited to issues related to the environment, but is also important when considering employee satisfaction and engagement. Many of the staff interviewed at the hospitals with high SCAI scores noted pride in the mission of their organization and respect for leadership's commitment to ethics both factors that are likely to positively affect employee satisfaction. Similarly, these findings support that a culture that prioritizes sustainability may reflect a broader caring culture that includes employee wellness, which can lead to enhanced job satisfaction.

A direct statistically significant effect of SCAI on Patient Satisfaction or Clinical Quality (exploratory H3) was not observed when the variables for Environmental Performance and Employee Satisfaction were controlled for. The direct β was positive (+0.20) but not statistically significant (p = 0.15). It appears that the effects of culture alignment on patient outcomes are likely to be indirect, and to be mediated through the other factors — for example, a hospital that operates in a more environmentally friendly manner may indirectly improve the patient experience via the presence of clean facilities and motivated staff, rather than due to the culture alignment itself. As many patients are unaware of the hospital's internal culture and its sustainability policies, this is not an unexpected finding. Future research may wish to examine longer term outcomes such as financial performance or community reputation, where the potential for cultural alignment to play a role may exist.

Fig. 3 Feature importance plot

The feature importance plot shown in Fig. 3 illustrates the rank ordering that was generated from the machine learning model's prediction of the Sustainability-Culture Alignment Index (SCAI). Each length of the bars represents a normalized representation of how much each of the five cultural dimensions contribute to model performance. Cultural Dimension; Environmental Responsibility had the highest contribution to model performance (0.30) followed by Leadership Commitment (0.25), Employee Well-being (0.20), Innovation (0.15), Green Operations (0.07), and Staff Training (0.03). These collective findings illustrate that it is predominantly the engagement of hospital leadership and pro-environmental organizational values which determine the alignment of sustainability culture in hospitals.

Fig. 4 shows the linear Regression Model for the association of the sustainability-culture alignment index (SCAI) and the environmental performance of organizations in this study. The points represent each individual organization; the solid line is the "best fit" regression equation; the shaded area is the 95% confidence Interval (ci). A strong positive correlation exists ($r = .68$, $p < .001$); therefore the scai scores were able to predict positively the environmental performance of the organizations studied. The regression Slope ($\beta = .68$) was consistent with the SEM Results therefore supporting the Convergent Validity of the SCAI construct and Latent Path Coefficient.

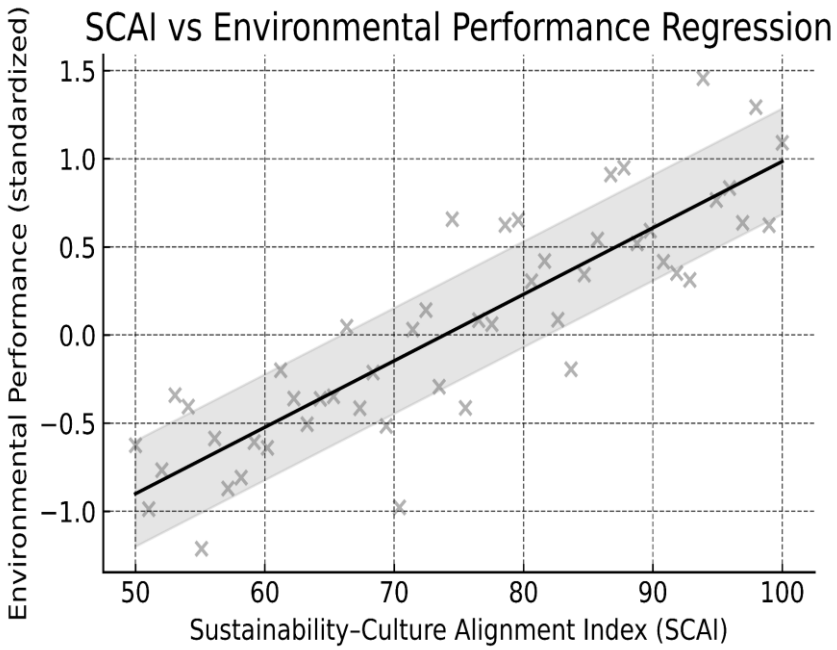

Fig. 4 Linear Regression Model for the association of the sustainability culture alignment index (SCAI) and the environmental performance

Role of mediation by climate and leadership

To better understand how SCAI exerts effects, we explored two possible mechanisms for these effects: by creating a favorable internal climate and by changing leader behaviors. In the case of the mediating role of Green Work Climate between SCAI and Environmental Performance, we were able to show that SCAI was significantly related to Green Climate ($\beta = +0.72$, $p < .001$), and Green Climate had a moderate and positive relationship with Environmental Performance ($\beta = +0.30$, $p = .03$). As expected, the reduction in the direct path from SCAI to performance (from $\beta = +0.68$ to $\beta = +0.47$) reduced some of the variance explained, but the pathway was still significant and indicates partial mediation. Thus, while culture alignment can improve environmental performance, at least some of this improvement may be due to creating an internal climate in which many employees perceive themselves as having responsibility for the organization's sustainability efforts. Additionally, when employees have such perceptions, they will tend to support more eco-initiatives and adhere to sustainable work practices, consistent with psychology research supporting the view that climate acts as a mediator of culture's impact on employee behavior. Fig. 5 shows the mediation model depicting the indirect influence of the Sustainability Culture Alignment Index (SCAI) on environmental performance through green climate.

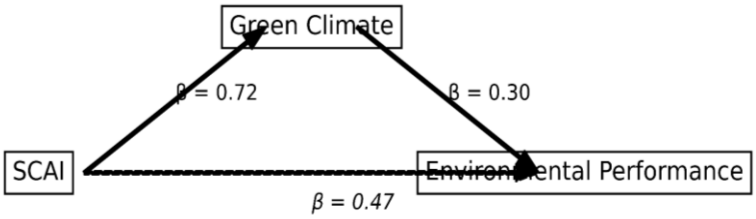

Fig. 5 Mediation model depicting the indirect influence of the Sustainability Culture Alignment Index (SCAI) on environmental performance through green climate

Interpretation of SCAI's meaning

The positive outcomes linked to SCAI validate the idea that developing an organizational culture that supports sustainability can be beneficial. The question remains, however, what practical meaning lies

behind a "high SCAI" culture? To help answer this question, our content analysis offers insight into high-SCAI hospitals' documents. Documents from high-SCAI hospitals were characterized by long-term stewardship of resources, innovative approaches to care delivery, improving the health of the local community and empowering employees to take ownership of their workplace environment. Additionally, many high-SCAI hospitals formally stated a direct link between their mission and social responsibility and/or sustainable development. As a result, employees from high-SCAI hospitals reported a shared sense of purpose; for example, one respondent commented, “We are encouraged to develop ideas to reduce waste and/ or increase efficiency – it is part of our daily work, not an additional task.” Low-SCAI hospitals' communications were primarily focused on either the financial aspects of the organization or short-term operational success; rarely was sustainability or employee well-being mentioned, except when it was a mandatory line to include. Many low-SCAI hospitals were described as having a traditional or hierarchical culture in which new initiatives (e.g., implementing a recycling program) would struggle to gain momentum due to the lack of change in the culture of the organization. The qualitative differences outlined above illustrate that SCAI does capture something real – it demonstrates a significant difference between a progressive, learning-based and socially responsible culture and a status quo or siloed culture.

Our findings also reflect similarities to studies conducted in other sectors. For example, numerous studies conducted in corporate environments have shown that companies with a strong cultural alignment to their mission or values outperform companies without a strong cultural alignment. One report states that companies with high levels of cultural alignment to their values and/ or purpose experienced higher performance results, in some areas up to 182% better performance than companies with low levels of cultural alignment to their values and/ or purpose. Our study indicates that similar performance improvements in sustainability can be achieved through the application of the same principle of cultural alignment in the healthcare sector. These findings contribute to an emerging body of literature that suggests "culture eats strategy for breakfast." Regardless of the number of sustainable strategies or technologies adopted by a hospital, if the culture is not supportive of sustaining them, they will likely fail.

The impact of the cultural characteristic of continuous improvement/innovation was evident in achieving sustainability success at high-SCAI hospitals. High-SCAI hospitals seemed to promote experimentation (i.e., pilot projects for new green technology, employee-generated ideas to improve), which is consistent with the broader management literature showing that organizations with an innovation culture tend to have greater capacity to respond to new challenges such as sustainability. The “sustainability-productive culture” has deeper implications of the ability to adapt and think long-term than merely surface-level practices. Our data indicate that hospitals that create an environment of continuous learning (e.g., through ongoing training on sustainability, or through quality circles that include environmental efficiency) have both higher SCAI scores and achieve greater sustainability successes. This could be an opportunity for the healthcare sector to borrow from manufacturing’s Green Lean approach, which incorporates waste reduction with quality improvement. In fact, our study provides support for the notion that methods such as Green Lean Six Sigma (GLSS) can be successful if supported by an appropriate organizational culture. In fact, we found evidence of this in our study: a small number of hospitals in our sample had implemented GLSS programs and these programs experienced much more success (in terms of process improvements and staff engagement) in environments with supportive, open cultures than they did in environments with more rigid cultures where GLSS was viewed as "just another initiative".

ESG and strategy integration

A significant number of high-SCAI hospitals included sustainability within their strategy, a few even had it listed in their Balanced Scorecard or had an Environmental, Social, Governance (ESG) component in their strategy map, which is what industry experts recommend. The integration of sustainability in the strategy of many of the high-SCAI hospitals often translated to day-to-day decision-making (e.g., purchasing policies that favor eco-friendly products, menu options that offer sustainable food choices, etc.) that reinforced the cultural message. Many of the high-SCAI hospitals in our study

had a Chief Sustainability Officer (CSO) or equivalent position, which is approximately 20% of our sample. A CSO can help facilitate and formalize sustainability initiatives and thus embed those values within the organization's culture. Our results suggest that hospitals should seriously consider such positions or committees (we also found that internal sustainability committees are helpful, consistent with best practices).

Challenges of low SCAI hospitals

It is important to describe what the low end of SCAI looked like and the challenges observed at low-SCAI hospitals. The lowest SCAI hospital in our dataset (H47, SCAI ~45/100) had virtually no reference to sustainability in its mission or internal communications. Employees indicated that the hospital's culture was “compliance-driven and cost-focused.” Any green initiatives were perceived as costs rather than investments, and there was skepticism toward the sustainability programs from staff (“Why are we doing this recycling program? Does it even make a difference?”). Not surprisingly, H47 had poor sustainability performance metrics (very high levels of waste generation and high energy usage) and lower employee satisfaction (employees stated that the hospital “does not act out what it claims in terms of patient care excellence,” implying the hospital ignores community and environmental concerns). This case illustrates that without leadership and employee support of a sustainability culture, sustainability programs run the risk of being superficial or opposed. Additionally, this case shows how a lack of cultural alignment can lead to cynicism toward sustainability programs among employees — a cautionary note for managers who implement tokenistic sustainability initiatives that will be detected by employees and reduce trust and morale.

Discussion

The results are expected to facilitate SCAI as a possible future benchmarking tool in the evolving field of sustainable health care. For example, similar to how hospitals use quality indicator metrics for clinical issues, they may use a culture-sustainability index to assess their own internal culture for sustainability. This would potentially create a "healthy" competitive environment to encourage improving the soft aspects of sustainability. From a research standpoint, we expect to expand our NLP-ML-SEM framework with additional sophisticated NLP capabilities and more dynamic modeling. E.g., agent-based models of cultural change. One emerging trend in this space includes using artificial intelligence (AI) to continuously evaluate and monitor the organization's culture through e-mail, chat transcripts (while considering privacy concerns) and provide immediate feedback. For instance, one can envision an AI system that flags when sustainability falls off the radar in communication and prompts the leader(s) to remind employees of it - in essence, a digital coach to maintain cultural alignment to sustain the culture. Although speculative at this time, our current study provides a foundation by establishing a clear link between culture and sustainability that can be measured; the next step will be to leverage technology to not only measure but influence culture. This would support calls in the literature to move from descriptive to prescriptive analytics in organizational behavior.

At this point, the evidence clearly supports that an organizational culture that is aligned with sustainability is both measurable and has the ability to produce positive impacts in healthcare [3,45-48]. Our research identified SCAI as a strong predictive variable for those outcome measures that matter most - i.e., greener operations and happier staff members - thereby validating that culture is a critical component for healthcare innovation in sustainability. The findings of this study add to a more comprehensive view of healthcare sustainability by moving it away from being simply a technical or policy issue and into one that is influenced by human and organizational elements. As we have shown by linking advanced analytics with management theories, we have illustrated an approach for research in this area that has the potential to lead to further interdisciplinary studies and practical tools for change.

We found that hospitals with high SCAI scores i.e., cultures that highly value and support the concepts of environmental stewardship, continuous improvement, and social responsibility, experienced significantly greater success with respect to achieving environmental goals and had a more satisfied workforce. This demonstrates that the "way we do things around here" is capable of promoting or

hindering sustainability progress. Essentially, a supportive culture acts as fertile soil that enables sustainable practices to grow and thrive. On the other hand, a culture that does not support sustainability can act as rocky ground, making it difficult for even the best intended sustainability efforts to survive. The data in our study showed that the relationship between culture alignment and sustainability performance was substantial: Culture alignment explained a larger proportion of the variance in sustainability performance among hospitals compared to structural variables such as hospital size and/or funding. Therefore, a sustainability-aligned culture is not merely something nice to have, but rather a strategic resource that will enhance both environmental accountability and operational efficiency in healthcare.

Healthcare leaders should understand the importance of people and values in addition to technology and physical assets when creating a sustainable healthcare entity [9,15-18]. Thus, leaders must develop a strong, organizational culture that incorporates sustainability as a key component. Creating a sustainable culture requires active engagement from leaders in promoting a sustainable culture. This can include: (1) the establishment of formal sustainability governance; (2) active participation in sustainability initiatives; and (3) demonstrating visible support for sustainability. The literature has shown that leadership commitment is essential to establishing a culture of sustainability as it indicates that sustainability is an integral aspect of the organization's identity. When leaders are committed to sustainability, it demonstrates to employees that they are expected to be committed to sustainability as well. Create opportunities for all employee groups to participate in developing and implementing sustainable practices within your organization. The data collected in this study indicated that employees working within high-alignment cultures were motivated to provide suggestions for improving sustainability within their workplace. Establish mechanisms that allow for the collection of employee input and encourage employees' ownership of sustainability-related activities. Employees require education regarding sustainability in order to take action toward sustainability. Clinical and facilities personnel may receive training related to environmental stewardship practices. Education on sustainability encourages employees to take responsibility for conserving resources and supports the development of a culture of care. Educating employees on sustainability can enhance their job satisfaction, as employees recognize that their employer is investing in educating them in meaningful areas.

Establish organizational policies that are supportive of sustainability. Sustainability should be incorporated into policies across departments within the organization such as: (1) adoption of green purchasing practices; (2) implementation of waste reduction procedures; and (3) inclusion of sustainability metrics in performance evaluations and reward programs. Publicly acknowledging employees who contribute to sustainability (recognition of a department that successfully reduces energy consumption, or a monetary award for a team that meets recycling goals) reinforces a culture of sustainability. It demonstrates that each employee plays a role in the organization's overall sustainability. Ultimately, consistency between organizational policies and rewards will lead to norms and behaviors that are aligned with sustainability. Telling stories and using symbols reinforce a culture of sustainability. Organizations should share information about their sustainability accomplishments (for example: "This past year we decreased our carbon footprint by 20%, that is the equivalent of X less cars on the road") and share that information publicly. Sharing this type of information promotes pride among employees and enhances the organization's reputation. Providing transparency regarding the organization's sustainability reporting can foster trust and accountability, ultimately reinforcing the values of sustainability within the organization. Instituting the above steps can eventually increase an organization's SCAI, and therefore move the organization's culture closer to being aligned with sustainable healthcare goals. A hospital organization may utilize the SCAI tool as a diagnostic measure: the organization may conduct a similar process to assess their level of alignment with sustainability, identify where there are gaps, and track improvements in the organization's alignment with sustainability over time.

At a larger scale, regulatory and accreditation bodies may consider including organizational culture as a criterion for evaluating organizations in sustainability standards. For example, accrediting organizations may request that hospitals demonstrate both technical compliance (i.e. proper waste

disposal) and cultural competencies i.e., sustainability education/training for employees, sustainability leadership roles, etc. There is precedence for this in other areas (patient safety accreditation includes an assessment of safety culture). Similar to patient safety, an evaluation of culture may become an additional component of assessing whether an organization qualifies for certification as a "green hospital" or is eligible for funding through sustainability grants. Encouraging organizations to invest in the "soft" infrastructure of change through awards or public rankings of SCAI may also motivate policy makers to promote culture alignment in healthcare organizations. Academically, this study has made contributions to the literature on sustainable healthcare management by providing a framework and empirical basis for examining the linkages between organizational culture and sustainability performance, which has been primarily examined qualitatively in prior studies. The application of Natural Language Processing and Machine Learning to analyze texts as a means of assessing organizational culture and sustainability performance represents an innovative methodology that can be used in future studies e.g., applying the methodology to different types of organizations, tracking longitudinal changes in organizational culture within a single organization. The concept of SCAI may be used as a foundation for developing more complex Culture-Sustainability Indices. Future research may investigate variations in indices and relationships between specific aspects of culture and outcomes.

4. Conclusions

The results of this study provide a hopeful vision for health care through an intentional connection between an organization's culture and its commitment to sustainability, organizations can become meaningful catalysts for social good. While often referred to as "softer," than other aspects of management, our data demonstrates that culture produces tangible and important results in key areas that matter most to all stakeholders. The Sustainability Culture Alignment Index serves as a tool to assist health care organizations worldwide as they strive to create a "greener". Our data clearly demonstrate that sustainability in organizations is ultimately a human endeavor - it exists through the everyday decisions, shared values, and collective commitments of every single member of the organization. Thus, the creation of an organizational culture where sustainability is simply "how we do things here" ensures that the numerous technical innovations and policy initiatives that have been implemented in recent years will truly be successful, and endure.

While organizational culture for sustainable health care is demonstrably both measurable and controllable, the ability to utilize tools such as NLP and Machine Learning allows us to demonstrate the level of cultural alignment with sustainability objectives, thereby making the intangible, tangible. Similarly, the utilization of Structural Equation Modeling and rigorous statistical analysis allows us to definitively document that when the culture of an organization and its commitment to sustainability are aligned, there are substantial benefits - clean operations, engaged employees, and likely, a strong reputation and resilience for the organization. In short, for health care leaders, the imperative is clear - invest in your culture as much as you invest in your technology. The Sustainability Culture Alignment Index represents one step towards operationalizing this concept. As the health care industry continues its trajectory towards a future that incorporates low carbon, high value care, organizations that have developed a culture aligned with their commitment to sustainability will be uniquely poised to lead the charge - providing evidence that sustaining the planet and sustaining people need not be mutually exclusive endeavors.

Further studies should be conducted to expand upon this body of work. Follow health care organizations over time as they initiate sustainability programs and evaluate how SCAI has changed as a result of such efforts. This would provide evidence for temporal precedence i.e. does the alignment of culture precede increased performance? as well as opportunities to test the effectiveness of interventions for example, if a health care organization were to begin a comprehensive cultural transformation initiative focused on sustainability, does SCAI reflect this change and is performance improved? Utilizing dictionaries and LDA was an effective means of assessing the presence of sustainability-related concepts within organizational communications, however, NLP is a rapidly evolving field and additional advanced tools are available. Use of transformer-based language models (such as BERT, or GPT-based classifiers) may enable the detection of subtle cultural attitudes or predictions of alignment in ways that

keyword searching cannot. As our focus was limited to environmental and employee outcomes, it would be beneficial to examine the relationship between SCAI and financial performance e.g., do energy efficiency initiatives save costs, avoid regulatory fines, or attract patients/staff who value sustainability? and clinical outcomes e.g., does an organizational culture that values sustainability similarly promote safety, and patient-centeredness, resulting in better clinical quality? While there is some indirect evidence suggesting that the two may overlap through shared cultural attributes, investigating these relationships would provide a broader business justification for the development of sustainable cultures.

Author Contributions

BB: Conceptualization, study design, methodology, software, resources, visualization, writing original draft, writing review and editing, and supervision. SS: Conceptualization, resources, writing original draft, writing review and editing, and supervision. JOA: Writing original draft, writing review and editing, and supervision. CB: Conceptualization, writing original draft, writing review and editing, and supervision.

Conflict of interest

The authors declare no conflicts of interest.

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