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Research Article

Confirmatory Factor Analysis of the Scale that Measures Energy Biosecurity Around the SDGs

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Abstract

Energy biosecurity, as a derivative of the Sustainable Development Goals (SDGs), has been included in the agenda of universities, although the measurement of its impact has not been established. In this sense, the objective of the present study is to confirm the factorial structure of an instrument that measures the impact of the SDGs in universities. A cross-sectional, correlational, psychometric and confirmatory study was carried out with a sample of 100 students, selected for their affiliation with institutions committed to the SDGs. The results show the confirmation of five dimensions related to knowledge and expectations of the SDGs, impact of clean energies, resilience to energy disasters and perception of energy efficiency, as well as 12 items of the nine factors and 27 items reported in the literature and measured by the instrument. The imponderables in the measurement of energy biosecurity are recognized and it is recommended to extend the instrument and the sample to confirm the theoretical structure.

Keywords: confirmatory factor analysis; energy biosecurity; sustainable development goals; risk perception

Introduction

The history of energy biosecurity is linked to the development of policies and strategies to protect energy infrastructure and ensure energy supply, while mitigating risks related to national security, the environment, and public health (Wieruszewski & Mydlarz, 2022). This evolution has had increasing importance in recent decades, as energy has become a strategic resource and globalization has made energy systems more interdependent and vulnerable. For much of the 20th century, energy security was primarily focused on securing the supply of fossil fuels, particularly oil, amidst a context of geopolitical tensions (Gilbert et al., 2021). The 1973 oil embargo was a flashpoint that highlighted the vulnerability of oil-dependent economies. Thereafter, countries such as the United States and other members of the Organisation for Economic Co-operation and Development (OECD) began to develop strategic and political reserves to diversify energy sources.

The modern concept of energy biosecurity emerged in parallel with the rise of renewable energy and growing concerns about threats to critical energy infrastructures such as power grids, pipelines and nuclear plants (Le *et al*., 2020). Energy biosecurity refers to the protection of these infrastructures from biological risks as well as natural and human threats (terrorism, sabotage, cyberattacks, etc.). As renewable energy (such as wind, solar, and biomass) began to gain relevance from the last decades of the 20th century and the beginning of the 21st century, energy biosecurity became more important (Alemu, 2020). These energy sources, although more sustainable, depend on technologically more complex and distributed infrastructures, which makes them vulnerable to various types of threats. In the 21st century, energy biosecurity has expanded to include concerns about climate change and the need to mitigate the environmental impact of energy production (Anderson & Bisanz, 2019). Extreme weather events, such as hurricanes, wildfires, and winter storms, can disrupt energy supply networks. Nuclear energy infrastructure also faces biological and environmental risks, such as the Fukushima disaster in 2011. Furthermore, the digitalization of energy systems has made critical infrastructures susceptible to cyberattacks (D'Amato, Bartkowski & Droste, 2020). Protecting these infrastructures has become a priority for many countries, with policies seeking to balance the transition to clean energy and the need to protect these critical infrastructures. In particular, energy biosecurity also refers to the production of energy from biomass, a renewable energy source that includes organic waste, plants, and other biological materials (Von Cossel *et al* ., 2019). While this source is promising, it also presents risks if not managed properly, such as the spread of diseases or soil degradation. Today, energy biosecurity is integrated into global sustainable energy strategies (Froldi, Ferronato & Prandini, 2023).

International organizations such as the International Energy Agency (IEA) and the United Nations promote policies that strengthen the resilience of energy systems to biological, climatic and technological threats (see Table 1).

Energy Biosecurity Dimension	Related SDG	Relationship Description
Diversification of energy sources	SDG 7: Affordable and clean energy	Promoting a diversification of sources (renewable, biomass, solar, wind) reduces dependence on fossil fuels and improves energy security, helping to ensure access to modern, affordable, reliable and sustainable energy for all.
Resilience to climate change	SDG 13: Climate action	Energy biosecurity includes measures to mitigate the effects of climate change on energy infrastructure, ensuring that energy systems can adapt and recover quickly from extreme weather events and protect the most vulnerable communities.
Protection of critical infrastructures	SDG 9: Industry, innovation and infrastructure	Ensuring the security of critical energy infrastructure against threats such as cyberattacks, sabotage or natural disasters fosters a solid and resilient infrastructure, essential for economic development and social stability.
Cybersecurity in energy networks	SDG 16: Peace, justice and strong institutions	Protection against cyberattacks on critical energy infrastructure ensures uninterrupted access to energy, avoiding conflict and social destabilization, and contributing to the construction of safer and fairer societies.
Sustainable biomass energy production	SDG 15: Life on land	The use of biomass as an energy source must be done in a sustainable manner so as not to compromise biodiversity, ecosystems and soils. Energy biosecurity seeks to mitigate these impacts and promote the protection of biodiversity.
Security of supply in vulnerable areas	SDG 1: End poverty	Ensuring access to affordable and safe energy in rural or vulnerable areas is crucial to eradicating poverty, as energy is essential for economic development, education and social well-being.
Mitigation of biological risks and pandemics	SDG 3: Good health and well-being	Energy biosecurity also encompasses the prevention of biological risks that may affect energy production and distribution, ensuring that pandemics do not disrupt energy supply, which is vital to guarantee efficient health systems.
Reducing dependence on fossil fuels	SDG 12: Responsible consumption and production	The transition to renewable and more sustainable energy sources minimises environmental impact, reduces the exploitation of non-renewable resources and promotes more responsible consumption patterns.
Transition to clean and sustainable energy	SDG 11: Sustainable cities and communities	Promoting the transition to clean and safe energy sources in urban environments improves air quality, reduces the carbon footprint and enhances quality of life, making cities more sustainable and resilient.
Energy efficiency and resource conservation	SDG 8: Decent work and economic growth	Improving energy efficiency through more advanced technologies not only reduces energy consumption, but also creates jobs in innovative and sustainable sectors, boosting economic growth without compromising the planet's resources.
Adaptation to natural disasters and extreme events	SDG 14: Life below water; SDG 11: Sustainable cities and communities	Protecting energy infrastructure from extreme events such as floods or storms minimizes the risks of environmental damage (oil spills, toxic emissions) and ensures the sustainability of coastal and rural cities and communities.

Table 1: Comparison of energy biosecurity dimensions around the SDGs

However, the dimensions of energy biosecurity have not been addressed from the risk perception surrounding the implementation of the SDGs in universities committed to these guidelines (Dili *et al*., 2022). Therefore, the objective of this work was to compare the theoretical structure of the perceptual dimensions with respect to the empirical observations of this work. Are there differences between the dimensions of energy biosecurity reported in the literature with respect to the dimensions perceived by students enrolled in universities committed to the implementation of the SDGs? This paper is based on the premise that the SDGs and energy biosecurity have been disseminated in the media and socio-digital networks, impacting risk perception in older audiences compared to young people (Ouko *et al* ., 2022) . Consequently, no differences are expected between the literature agenda and the university agenda.

Method

Design: A cross-sectional, exploratory, psychometric and confirmatory study was conducted with a sample of 100 students selected based on their affiliation with institutions committed to the SDGs. Instrument. The Energy Biosecurity Perception Scale was used (see Annex A). It includes the following dimensions: 1) Knowledge of the SDGs, 2) SDG Expectations, 3) Infrastructure Security Assessment, 4) Perception of Unsustainable Energies, 5) Impact of Clean Energies, 6) Expectations of Biomass Loss, 7) Resilience to Energy Disasters, 8) Perception of Energy Efficiency, 9) Perception of Energy Cybersecurity. Procedure. Students were invited to participate in focus groups to homogenize the concepts of the instrument (Reid *et al*., 2019). They were invited to evaluate the items using the Delphi technique (Plowright *et al*., 2008). They were informed about the objectives and responsibilities of the project (Mitra, 2020). The survey was applied at the university facilities (O'Shea *et al*., 2024). They were warned that their participation would not be remunerated and would not affect their academic status.

Analysis: Data was captured in Excel and processed in Google Colab using Python coding (see appendix B). Reliability, adequacy, sphericity, linearity, homoscedasticity, normality, validity, adjustment and residual parameters were estimated.

Results

The analysis of covariances between the factors indicates the contrast of the theoretical structure with respect to the empirical observations (see Fig. 1). The results show values close to unity, which are assumed as evidence of non-rejection of the hypothesis of differences between the theoretical structure and the observations of the present study. In addition, the non-inclusion of other reagents in the empirical structure is inferred.

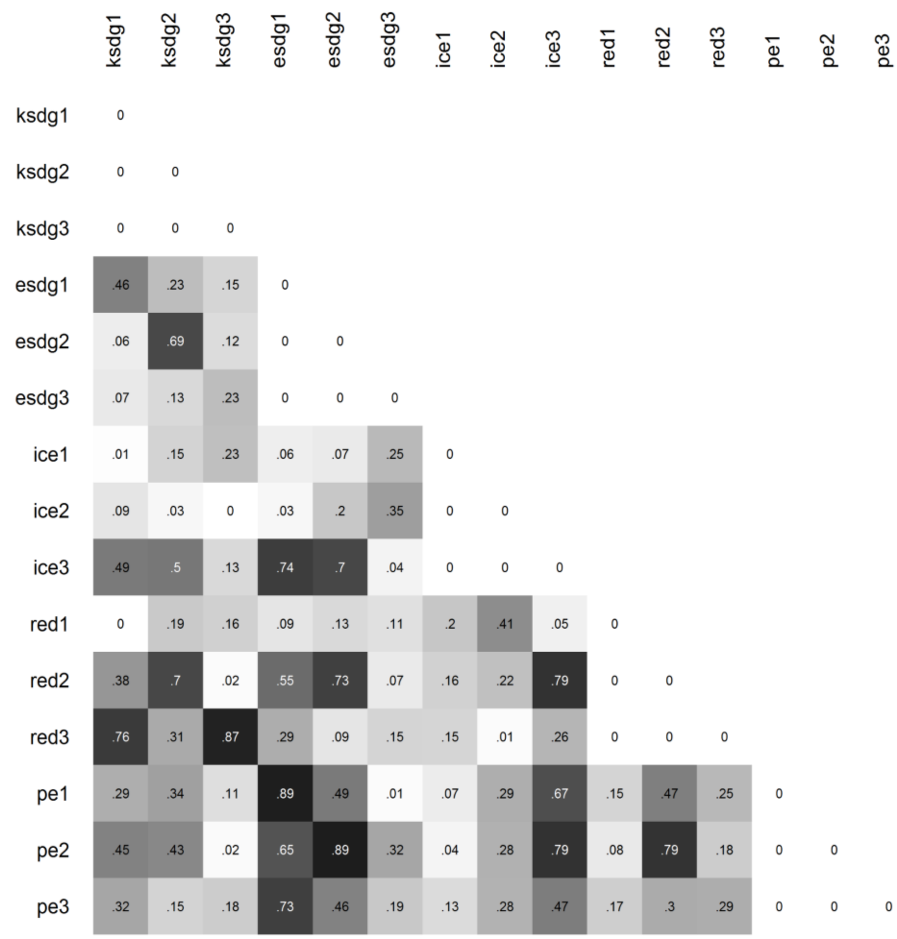

Figure 1: Covariances between indicators

Structural analysis suggests confirmation of the relationships between the factors and indicators (see Fig. 2). The factor structure includes three cases of overestimation of the relationships between the first indicator of knowledge and expectations of the SDGs, as well as the first indicator of the factor related to the perception of energy efficiency. It is recommended to replace the items in order to confirm the five-factor factor structure with its corresponding 15 items.

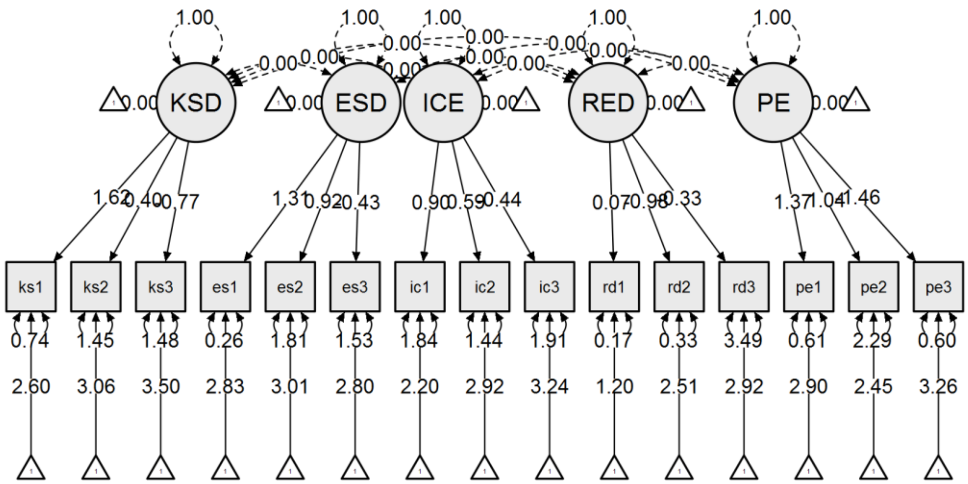

Figure 2: Confirmatory factor model of energy biosecurity around the SDGs

The fit and residual parameters [x2 = 1626.366 (90 gl) p < 0.001; RFI = 1.000; FI = 0.907; RMSEA = 0.000] suggest non-rejection of the hypothesis regarding differences between the structure of SDG energy biosecurity expectations with respect to the empirical observations of this work.

Discussion

The contribution of this work to the state of the art lies in the confirmation of a structure of five factors and 12 indicators with respect to the structure of nine factors and 27 indicators reported in the literature on the perception of energy biosecurity. The intersection of biosecurity, energy and the Sustainable Development Goals (SDGs) is crucial in the context of the growing global bioeconomy (Meyer *et al*., 2020). Microalgae play an important role in achieving SDG-6 (Clean Water and Sanitation), SDG-7 (Affordable and Clean Energy) and SDG-13 (Climate Action). Implementing a green economy is essential for sustainable development and investment, as seen in the support provided to Mongolia by the United Nations Environment Programme. The production of sustainable aviation fuels is proposed as a solution to reduce aviation's dependence on liquid fossil fuels, highlighting the importance of clean energy (Fajemisin & Ogunribido, 2018). Innovation in achieving the 17 UN SDGs, including energy-related goals, is crucial for sustainable development. The future of food and agriculture is closely linked to the way energy is produced and distributed, highlighting the need for sustainable energy sources. Renewable energy plays a key role in the total primary energy supply, contributing to sustainable energy practices. Biosecurity and bioforensics are essential components to ensure sustainable practices in nuclear and chemical sciences (Herron *et al* ., 2021) . Promoting inclusive and sustainable regions is vital to unlock the potential of entrepreneurs and small and medium-sized enterprises in the energy sector. Research on the impacts of global change on biodiversity and biosecurity contributes to achieving SDG 2 (Zero Hunger). Companies are focusing on biosecurity, energy consumption and environmentally friendly solutions in their operations, aligning with sustainable development practices. Unlike the state of the art, which states the close relationship between the SDGs and the dimensions of energy biosecurity, this work suggests that only five of the nine dimensions and 12 of the 27 items can be confirmed as a factorial structure. However, it is recognized that the measurement of the unconfirmed dimensions and items may be biased by the lack of dissemination of the SDGs in universities, the focus of universities on some SDGs, or errors inherent to the instrument. Therefore, it is recommended to replace the items that were not confirmed and structure their relationships with the corresponding factors. To this end, increasing the scale and the sample will allow achieving the purpose of confirming the scale.

Conclusion

The objective of this work was to contrast the hypothesis of differences between the theoretical structure and empirical observations related to energy biosecurity derived from the SDGs. The results demonstrate the confirmation of five dimensions with 12 items of nine factors and 27 reagents reported in the consulted literature. Imponderables are recognized in the measurement of energy biosecurity in universities committed to the implementation of the SDGs. It is recommended to extend the instrument and the sample in order to increase the validity of the items and factors in order to confirm their structure.

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Annex A

Scale Dimensions:

1. Knowledge and understanding of the SDGs

- Assesses the level of knowledge and familiarity with the SDGs, particularly those related to energy and climate (SDG 7, SDG 13).

- Example item: "How familiar are you with the SDGs related to energy and climate change?"

2. Perception of climate risk and its impact on university infrastructure

- Measures how respondents perceive the impact of climate risks (floods, droughts, storms) on the university's energy infrastructure.

- Example item: "How vulnerable do you consider the university's energy infrastructure to be to climate-related natural disasters?"

3. Critical infrastructure security assessment

- Analyzes the perception of security of the university's energy infrastructure against physical or cyber threats.

- Example item: "How protected do you think the university's energy infrastructure is from threats such as cyber attacks or sabotage?"

4. Perceived risk in dependence on non-sustainable energy sources

- Examines the perception of risk arising from dependence on fossil fuels or non-renewable energy sources on campus.

- Example item: "Do you consider it risky for the university to depend mainly on non-renewable energy sources?"

5. Impact of the transition to clean energy

- Measures the perception of risk associated with the transition to renewable energy within the university, including costs, technical feasibility, and the impact on daily activities.

- Example item: "How risky do you consider the transition to renewable energy within the university?"

6. Perception on biomass and sustainability

- Evaluates the degree of perceived risk in the implementation of biomass-based energy sources on campus and their environmental impact.

- Example item: "How viable do you consider the production of energy from biomass at the university without compromising the sustainability of ecosystems?"

7. Resilience to natural disasters

- Assesses the perception of the university's capacity to deal with extreme weather events that affect energy supply.

- Example item: "How prepared do you think the university is to maintain power supply during a natural disaster?"

8. Energy efficiency and resources

- Measures the perception of risk associated with energy inefficiency and excessive use of resources in university facilities.

- Example item: "How worrying is energy inefficiency at the university and the impact on available resources?"

9. Energy cybersecurity

- Measures the level of concern about the vulnerability of energy systems to cyberattacks.

- Example item: "How risky do you consider the university's energy system to be in terms of protection against cyberattacks?"

10. Institutional commitment to the SDGs

- Assesses the perception of the university's commitment to the implementation of the SDGs, particularly in relation to energy sustainability.

- Example item: "How committed do you consider the university to be in the implementation of the SDGs, especially in relation to clean energy?"

Scale Structure

- Response Range: The scale can use a 5-point Likert format, where 1 is "Very low" or "Not at all agree" and 5 is "Very high" or "Totally agree."

- Degree of Risk: A component can be added that measures the "perceived degree of risk", categorizing each item into:

- Low: The risk is perceived as insignificant or controllable.

- Moderate: There is some concern, but it is believed that the risks can be mitigated.

- High: The risk is perceived as significant and difficult to control without major intervention.

Appendix B

```
# Install the library needed to work with ODS files
!pip install odfpy
# Import the necessary libraries
import pandas as pd
import matplotlib.pyplot as plt
from odf.opendocument import load
from odf.table import Table, TableRow, TableCell
from odf.text import P
# Upload the ODS file (make sure you upload it or have it in your directory)
file_path = '/mnt/data/SEM CFA Security.ods'
# Read the ODS file
def read_ods(file_path, sheet_index=0):
spreadsheet = load(file_path)
sheets = spreadsheet.getElementsByType(Table)
sheet = sheets[sheet_index]
data = []
for row in sheet.getElementsByType(TableRow):
row_data = []
for cell in row.getElementsByType(TableCell):
repeat = int(cell.getAttribute("numbercolumnsrepeated") or 1)
for _ in range(repeat):
```

```
text_content = "".join([str(t.data) for t in cell.getElementsByType(P)])
row_data.append(text_content)
data.append(row_data)
return pd.DataFrame(data)
# Load the data sheet (you can change the sheet number if there are several)
df = read_ods(file_path, sheet_index=0)
# Display the first rows of the DataFrame
print(df.head())
# Clean data if necessary (replace null values, remove empty columns, etc.)
df_clean = df.dropna(how='all', axis=1) # Remove completely empty columns
df_clean = df_clean.dropna(how='all', axis=0) # Delete completely empty rows
# Show the first rows after cleaning
print(df_clean.head())
# Suppose the risk dimensions are in different columns.
# Create basic visualizations (for example, distributions or bar charts)
# Display the distributions of some dimensions (put the real name of the columns)
# Example for the first 5 columns
df_clean.iloc[:, 1:6].plot(kind='bar', figsize=(10, 6))
plt.title('Distribution of energy biosecurity dimensions')
plt.xlabel('Answers')
plt.ylabel('Frequency')
plt.legend(loc='upper right')
plt.show()
# Basic statistical summary
print(df_clean.describe())
# Correlation analysis between risk dimensions
correlation_matrix = df_clean.corr()
print(correlation_matrix)
# Visualizing the correlation matrix
import seaborn as sns
plt.figure(figsize=(10, 8))
sns.heatmap(correlation_matrix, annot=True, cmap='coolwarm')
plt.title('Correlation matrix between risk dimensions')
plt.show()
```