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Published in:
Journal of Environmental Management

DOI:
10.1016/j.jenvman.2023.118328

Published: 15/10/2023

Document Version
Publisher's PDF, also known as Version of record

Journal of Environmental Management 344 (2023) 118328

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Reducing SDG complexity and informing environmental management education via an empirical six-dimensional model of sustainable development

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ARTICLE INFO

Keywords:
Environmental education for sustainable development
SDG complexity
Sustainability models
Pillars of sustainable development
Thematic analysis
SmartPLS

ABSTRACT

Effective environmental management higher education programs are essential for achieving the Sustainable Development Goals (SDGs). Yet SDG complexity means many educators focus on environment and avoid critical but challenging social, economic and governance aspects. This undermines the calls for comprehensive environmental management education that effectively integrates all key sustainability dimensions. Various sustainability models, mostly founded on the pillars of sustainability, have consequently evolved. They are generally conceptual and/or involve subjective categorization of the SDGs, which has led to demands for more empirically based models. This study has consequently used a mixed-method approach to model Australian university students' SDG perceptions. The qualitative research identified three items (on average) for each SDG, and a quantitative survey then measured their perceived importance. Factor analysis generated a robust six-dimensional sustainable development model comprised of 37 SDG items, which validates environment and governance aspects of some traditional pillar-based sustainability models. It has also uncovered new social and economic dimensions: social harmony and equality; sustainable consumption and socioeconomic behaviors; sustainable production, industry and infrastructure; and acute poverty reduction. These findings can help educators, organizations and citizens to categorize and integrate SDGs via better understanding of their key dimensions and impacts.

1. Introduction

Environmental management higher education that effectively promotes sustainable development is essential to impart pro-sustainable behaviors and address worsening global environmental and social conditions (Ajibade and Boateng, 2021; Bardsley et al., 2022; Obrecht et al., 2022). Such education will guide future environmental management educators, researchers and practitioners, who must increasingly consider policy and practice based on a range of sustainability goals (e.g. Germann et al., 2023; Koley, 2023). However, the multifaceted nature of sustainability and the plethora of goals present an array of implementation challenges (Balaras et al., 2020).

The United Nations, 2022b Sustainable Development Agenda (2030 Agenda) consequently provides a roadmap for tackling global environmental, social and economic challenges (United Nations, 2015). However, "crisis multiplier" effects of the COVID-19 pandemic, the war in Ukraine, and accelerated climate change have put its 2030 targets in jeopardy (United Nations, 2022a, p. 2). Global greenhouse gas emissions are expected to rise by around 14% in the next decade, and this coupled with slowed economic growth and inflation, and corresponding increases in poverty, hunger and political instability, will likely mean reduced investment in and prioritization of sustainable development (United Nations, 2022a).

Research advancing environmental management and sustainable development education is crucial for getting the 2030 Agenda back on track (United Nations, 2022a). Research that assures more informed environmental management education (Kurokawa et al., 2023) and overcomes efficacy barriers of such education is an urgent priority (Foley, 2021).

A major barrier to effective environmental management education for sustainable development relates to the complexity of sustainability and corresponding Sustainable Development Goals (SDGs). For

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https://doi.org/10.1016/j.jenvman.2023.118328
Received 21 March 2023; Received in revised form 23 May 2023; Accepted 4 June 2023
Available online 18 June 2023

example, tensions between different sustainability dimensions and goals (UNESCO, 2020) can create challenges for educators, including informing and evaluating appropriate environmental policy (Germann et al., 2023; Marra, 2022). Such SDG complexity is why many universities struggle to incorporate effective sustainability education into their curricula (Kioupi and Voulvoulis, 2019; Leal Filho et al., 2021). This may also explain why many teachers feel unable to teach sustainable development themes (United Nations, 2022a), while others focus entirely on environmental aspects of sustainability with which they are better acquainted (Obrecht et al., 2022). Comprehensive environmental management education for sustainable development, including corresponding policies and practices, must integrate environmental, social, and economic themes (de Andrade Guerra et al., 2018; Obrecht et al., 2022), which requires transdisciplinary aptitude (Marra, 2022). Further research is therefore urgently needed to overcome the challenges of SDG complexity (Horvath et al., 2022; Jiang et al., 2022).

This research has used a sequential, mixed-methods approach to generate deeper understanding of higher education student SDG perceptions, identifying the core underlying goal dimensions in a new empirical model. This reduces SDG complexity and will assist with the development of environmental management degrees that more effectively promote sustainable development. It will also inform individual sustainability courses that are often embedded in and common to other degrees (e.g. Greenland et al., 2022).

2. Review of related research

2.1. SDG complexity

The SDGs introduced by the United Nations in 2015 have helped unite governments globally in a commitment to a common sustainable development agenda (United Nations, 2022a). Although there has been much criticism of their complex nature, including their interlinkages that present multiple implementation challenges for educators, practitioners and policymakers (Germann et al., 2023; Jiang et al., 2022; Spaiser et al., 2017).

The 17 SDGs and their 169 associated targets (United Nations, 2022b) have been described as unmanageable and unwieldy (Szirmai, 2015), confounding decision-makers trying to navigate so many goals and targets, which can impede the development of appropriate environmental policy and sustainability initiatives (Germann et al., 2023; Horvath et al., 2022). Many of them overlap, which further impedes the implementation of coherent education for sustainable development programs (Kioupi and Voulvoulis, 2019; UNESCO, 2020). For example, such overlap increases the likelihood of duplicating sustainability efforts, which creates further confusion and undermines the SDGs and the 2030 Agenda (International Institute for Sustainable Development, 2019).

Another common criticism relates to the incompatibility of some SDGs, such as the contradiction between economic, social, and environmental SDGs (UNESCO, 2019). Qasim and Grimes (2022) highlighted the conflict between often-costly social goals that support welfare and those focused on economic development, while Spaiser et al. (2017) described the mismatch between socioeconomic goals and those focused on environmental sustainability. For instance, even if socioeconomic development is more sustainable in nature, it invariably means greater resource depletion.

Fig. 1 summarizes the perceived incompatibility of environmental SDGs against the other economic and social SDGs. Even where an environmental conflict may not be immediately apparent (e.g. SDG 5. Gender equality, SDG 10. Reduced inequalities, SDG 16. Peace, justice and strong institutions, SDG 17. Partnerships for the goals), such facilitation of social and economic development is likely to lead to greater negative environmental impacts. This incompatibility causes confusion for educators and organizations, as well as citizens, creating challenges to reconcile such differences (UNESCO, 2020).

Further complexity relates to interpreting and adapting SDGs to country-specific contexts, including localized sustainable development challenges (e.g. Balaras et al., 2020; Tonegawa, 2023). There is also often shifting prioritization of SDGs due to changing market conditions.

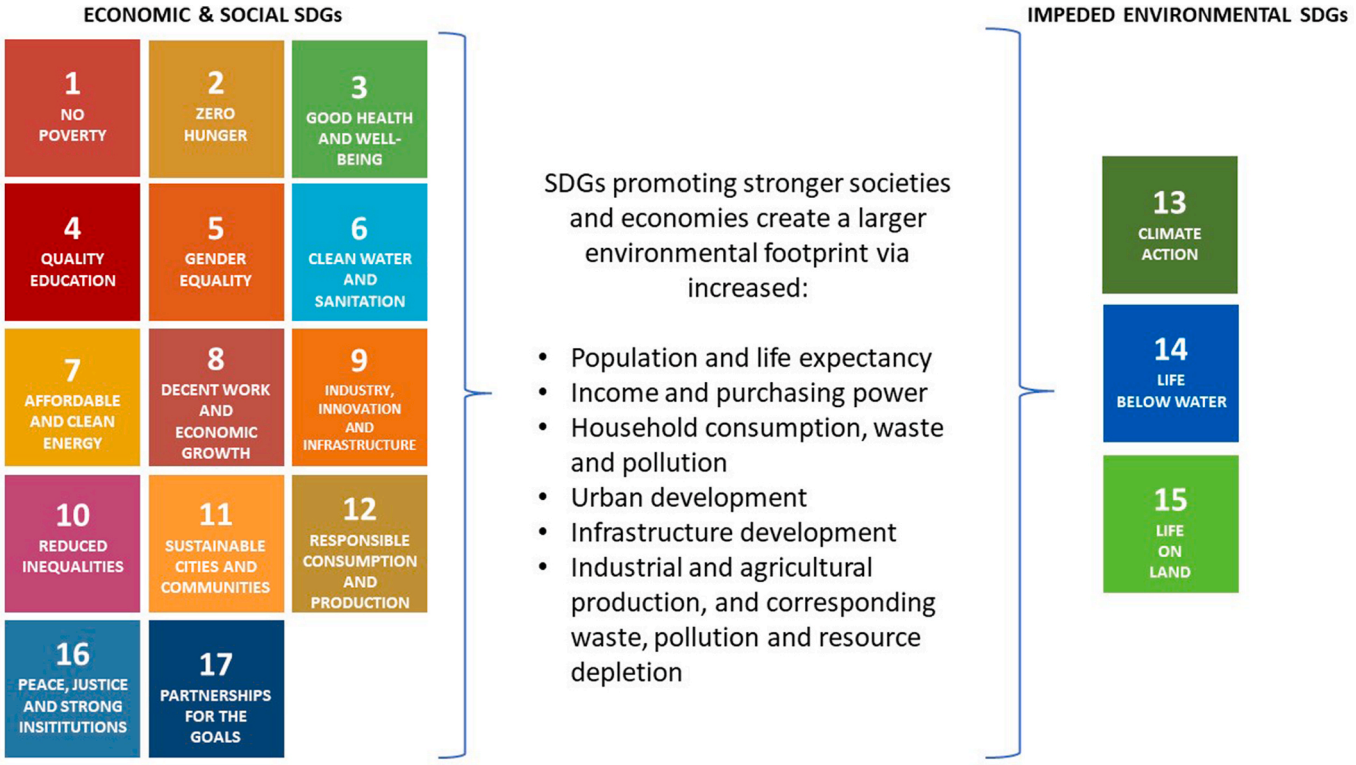

Fig. 1. Incompatibility of economic and social SDGs with environmental goals.

For example, when there is extreme poverty many SDGs such as those relating to education are likely to become less relevant (UNESCO, 2020). Furthermore, recent accelerated climate change, natural disasters, the COVID-19 pandemic, and the war in Ukraine have intensified food, energy, and humanitarian challenges, which have resulted in survival situations in many countries, undermining sustainable development plans and initiatives (United Nations, 2022a).

2.2. Environmental management higher education for sustainable development

Effective environmental management higher education is a proven driver of pro-sustainable behaviors (Ajibade and Boateng, 2021; Kurokawa et al., 2023) and is central to achieving the SDGs (Foley, 2021). It shapes sustainable citizen behaviors and builds organizational competencies in environmental and social responsibility (e.g. Kolb et al., 2017). Yet SDG complexity means many stakeholders struggle to develop and implement effective responses to achieve them (Dziubaniuk et al., 2022). In higher education this has hindered the education for sustainable development programs (Tejedor et al., 2018), with more research required (Nguyen et al., 2019).

Because of SDG complexity, many higher education institutions have focused on the sustainability aspects perceived to be more accessible, influencing a mostly biological or geographical perspective (Kankovskaya, 2016). This demonstrates avoidance of more challenging social-economic-environmental SDG complexities, with the root causes of the global sustainability crisis not adequately addressed. More research is therefore required to facilitate environmental education programs in higher education that more effectively integrate the social, economic, and environmental dimensions (de Andrade Guerra et al., 2018).

2.3. Overcoming SDG complexity

2.3.1. Conceptual frameworks and qualitative models

To help address the complexity of SDGs and sustainability, numerous studies have created frameworks or models. Some of these have reduced the real-world complexity to a limited number of sustainability dimensions, helping educators to simplify SDG decision-making and inform their programs (e.g. Brundiers et al., 2021). They have generally drawn on the three pillars of sustainable development (social, economic and environmental), with emphasis on the need for balance or equilibrium between them (e.g. Hansmann et al., 2012). Others have included an additional fourth political or governance pillar (e.g. Zhang, 2013). These models have helped to overcome the often-narrow environmental focus of sustainable education (e.g. Parry and Metzger, 2023).

Other frameworks have focused specifically on the SDGs rather than the pillars of sustainability. For example, Tonegawa (2023) highlighted SDG 4 (quality education) as the crux for achieving all the other SDGs. In line with this, Kolb et al. (2017) produced an SDG pyramid model that positions SDG 4 at the top, which illustrates how quality education in terms of improving managers' sustainability understanding immediately impacts SDGs 8 (decent work and economic growth), 9 (industry, innovation and infrastructure), 12 (responsible consumption and production), and 17 (partnerships for the goals). The second layer then has positive, innovation-related impacts on SDGs 6 (clean water and sanitation), 7 (affordable and clean energy), 14 (life below water), and 15 (life on land). These in turn impact on the last layer comprising SDGs 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 5 (gender equality), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action), and 16 (peace, justice and strong institutions).

Other models have combined the sustainability pillars and SDGs, with the goals categorized according to the pillars (e.g. Barta et al., 2023). For example, in Rockström and Sukhdev's (2016) model of sustainable development (see Fig. 2), the SDGs are divided by the traditional three pillars, with economic and social (society) embedded within the environment (biosphere). At the top sits SDG 17 (partnerships for the goals), with economic (SDGs 8, 9, 10, 12), social (SDGs 1, 2, 3, 4, 5, 7, 11, 16), and environmental (SDGs 6, 13, 14, 15) ordered below.

2.3.2. Quantitative approaches and empirical frameworks

Criticism of the conceptual frameworks and qualitative models often concerns the use of pre-existing ideas that lack any theoretical foundation (Sebestyén et al., 2019). Some researchers have consequently used quantitative approaches, such as Hansmann et al. (2012) who applied factor analysis to confirm the validity of the traditional three-pillar sustainability model. In contrast, Greenland et al. (2022) empirically derived a five-pillar model of sustainability based on students' perceived importance of sustainability concerns, and then mapped the SDGs across these pillars.

Yet SDG categorization has continued to attract criticism, because it is based on qualitative, subjective judgment, meaning such SDG mapping against pillars could vary from researcher to researcher (Sebestyén et al., 2019). In line with this, Greenland et al. (2022) acknowledged that assigning SDGs to the five sustainability pillars was open to interpretation, given their significant overlaps.

The SDGs have also been criticized for lacking theoretical foundation (e.g. Szirmai, 2015). This includes the need for systematic, research-based classification of SDGs (e.g. Greenland et al., 2022; Spaiser et al., 2017), to generate frameworks to facilitate their inclusion in higher education programs (Leal Filho et al., 2021). This research responds to the literature gap with its empirical model of SDGs, generated from Australian higher education student perceptions of the importance of SDG dimensions.

Examination of student SDG perceptions is a significant sustainable development research avenue (Leal Filho et al., 2021). For example, improved understanding of student SDG perceptions is essential for integrating them into curricula (Boarin et al., 2020; Wersun et al., 2020). This supports constructivist learning principles, where establishment of a pre-existing understanding is the starting point for education development (Baviskar et al., 2009). That is once students' SDG perceptions are understood, then education programs can be designed to build on this knowledge. Additionally, alignment with the 2030 Agenda (United Nations, 2015) can facilitate sustainability models, which further improve understanding and serve as educational planning tools (Biggs, 2014).

This study has adapted the former research approach by Greenland et al. (2022), which investigated perceptions of sustainability, to measure perceived importance of SDGs among higher education students. An empirically derived SDG model was then developed to further inform education for sustainable development and corresponding business practices.

3. Method

3.1. Research approach and context

A sequential mixed-method approach was used in this study, to combine the advantages of both qualitative and quantitative research (e.g. Hossain et al., 2019) and to facilitate the development of robust research instruments (e.g. Lima Santos et al., 2020).

The research context was a public higher education institution in Australia – Charles Darwin University (CDU) – which is a signatory to the United Nations SDGs. Such use of a single institutional case is common in education for sustainable development research (Nwagwu, 2020). Research was conducted in accordance with ethical research standards, with approval from CDU's Human Research Ethics Committee. The research targeted convenience samples of undergraduate and postgraduate students in the Faculty of Arts and Society. These students study a range of degrees including arts, business, education, and humanities – all undertake a common sustainability course that is embedded in and common to all CDU degrees.

Fig. 2. Adaptation of Rockström and Sukhdev's (2016) wedding cake model of sustainable development.

3.2. Phase 1: exploratory online qualitative research

The initial qualitative phase investigated student perceptions of the 17 SDGs, to identify the key themes or dimensions that represented each goal. This exploratory phase followed a format used in prior sustainability studies (e.g. Greenland et al., 2021, 2022) and comprised two 90-min focus group discussions (five participants each) and 44 online individual in-depth interviews. The 54 participants, according to Fugard and Potts' (2015) qualitative sample size tool, provided a robust sample to generate detailed insights.

The focus groups and in-depth interviews were conducted online via the Blackboard Collaborate synchronous discussion function in CDU's learning management system (LMS). The focus group discussions were recorded and transcribed immediately afterwards. Adhering to computer-assisted self-interview protocol (e.g. Cooper and Schindler, 2006), the interview participants provided written responses via an online link that was sent to their CDU emails.

Both the focus group and in-depth interview participants were asked the same open-ended questions about their perceptions and understanding of each SDG. They were shown the SDG title and associated description, as presented on the United Nations website (United Nations, 2022b), and were then asked to describe what came to mind when they thought about what each SDG means.

3.2.1. Qualitative analysis to identify SDG items to include in the survey

Qualitative data analysis was conducted using both automated and manual approaches as recommended in the literature (e.g. de Graaf and van der Vossen, 2013). The Leximancer automated content analysis software, deemed appropriate for analyzing larger volumes of qualitative data (Wilk et al., 2019), was first used to identify obvious themes, as a starting point for the manual analysis (Greenland et al., 2021). Yet despite its successful application in other studies by these researchers, Leximancer did not provide any meaningful interpretation of the data, perhaps due to the number of SDGs and their interrelated nature. The analysis therefore moved onto manual thematic analysis, where all responses were read through to identify key themes, which were then counted and sorted by order of frequency of mention (Namey et al., 2007).

The key themes that reflected participant perceptions of each SDG were subsequently identified, for inclusion in the survey for the quantitative phase of the research.

3.3. Phase 2: online quantitative survey

A self-completion questionnaire was administered using the Qualtrics online survey platform via a survey link and a research information statement that were sent to a convenience sample of faculty students.

3.3.1. Survey design

The number of questionnaire items was limited to keep the survey at an acceptable length to maintain data reliability by avoiding respondent fatigue, and to reduce nonresponse bias (e.g. Jepson et al., 2005). Entry into a prize draw was also offered as an incentive to enhance the response rate (e.g. Greenland et al., 2022).

For self-completion online surveys, an average duration of 12 min has been cited as the point where response rates dip (Qualtrics, 2022). The researchers' prior experience with other Qualtrics surveys suggested that keeping the survey to this duration dictated around a maximum of 50 rated items in addition to general behavior and demographic questions, which appeared before and after the battery of @50 items.

The researchers subsequently sought to identify the top three mentioned themes that emerged during the qualitative phase for each SDG. Yet the widely reported overlap of SDGs (e.g. Kioupi and Voulvoulis, 2019) resulted in the duplication of some items, where the same themes emerged for separate goals. For example, poverty and having enough money to buy essentials were themes that emerged in multiple SDGs (e.g. SDG 1. No poverty, 2. Zero hunger, 3, good health and well-being, 8. Decent work and economic growth, and 10. Reduced inequalities). To avoid item duplication in the questionnaire, such items were presented only once with the SDG that received the most participant mentions. In cases where the frequency of theme mentions was the same for different SDGs, the researchers assigned the item to the SDG viewed as most applicable. Through this process, the 50 items and associated SDGs presented in Table 1 below were identified for inclusion in the questionnaire.

To further illustrate aspects of SDG overlap encountered during the

Table 1
SDGs and related themes identified for inclusion in the questionnaire.

SDG no.	SDG title, description[a] and corresponding questionnaire items[b]
1	**NO POVERTY – End poverty in all its forms everywhere**
	End poverty everywhere
	Enough money to satisfy all essential life costs
2	**ZERO HUNGER – End hunger, achieve food security and improved nutrition, and promote sustainable agriculture**
	End hunger everywhere
	Healthy foods available to all
	Innovation for sustainable agriculture
3	**GOOD HEALTH AND WELL-BEING – Ensure healthy lives and promote well-being for all at all ages**
	Promote well-being for all
	Healthy lifestyle
	Quality healthcare for all
4	**QUALITY EDUCATION – Ensure inclusive and equitable quality education, and promote lifelong learning opportunities for all**
	Quality educational for all
	Sustainability education for all (e.g. climate change, pollution)
5	**GENDER EQUALITY – Achieve gender equality and empower all women and girls**
	End gender inequality
	Women empowerment
	End domestic violence
6	**CLEAN WATER AND SANITATION – Ensure availability and sustainable management of water and sanitation for all**
	Clean water for all
	Sanitation for all
	Sustainable water management practices
7	**AFFORDABLE AND CLEAN ENERGY – Ensure access to affordable, reliable, sustainable and modern energy for all**
	Affordable and clean energy available to all
	Renewable energy (move away from fossil fuel)
8	**DECENT WORK AND ECONOMIC GROWTH – Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all**
	Sustainable economic growth
	Decent employment opportunities for all
9	**INDUSTRY, INNOVATION AND INFRASTRUCTURE – Build resilient infrastructure, promote sustainable industrialization, and foster innovation**
	Sustainable innovation for industry
	Sustainable business and industry practices
	Sustainable infrastructure for business
10	**REDUCED INEQUALITIES – Reduce inequality within and among countries**
	Reduce economic gaps between developed and developing countries
	Support the disadvantaged and vulnerable
	End racism and cultural inequality
11	**SUSTAINABLE CITIES AND COMMUNITIES – Make cities and human settlements inclusive, safe, resilient and sustainable**
	Sustainable transport systems
	Public safety and security
	Public recreation facilities for all
	Smart (sustainable) cities
12	**RESPONSIBLE CONSUMPTION AND PRODUCTION – Ensure sustainable consumption and production patterns**
	Sustainable production of goods and services
	Energy saving behavior
	Recycling behavior
	Sustainable consumption behavior
13	**CLIMATE ACTION – Take urgent action to combat climate change and its impacts**
	Combat climate change
	Reduce global warming
	Reduce air pollution
14	**LIFE BELOW WATER – Conserve and sustainably use the oceans, seas and marine resources for sustainable development**
	Reduce water pollution (rivers, seas and oceans)
	Preserve ocean biodiversity and ecosystems
15	**LIFE ON LAND – Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**
	Preserve biodiversity and ecosystems on land
	Reduce deforestation and land degradation
	Reduce land pollution
16	**PEACE, JUSTICE AND STRONG INSTITUTIONS – Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels**
	Global peace
	Diversity and social harmony
	Fair laws and justice for all
	Industry regulation and accountability
	Accountable governments and public institutions
17	**PARTNERSHIPS FOR THE GOALS – Strengthen the means of implementation and revitalize the global partnership for sustainable development**
	Global partnerships for sustainable development
	Government sustainability policy
	International support for sustainability in developing countries

[a] United Nations, 2022b
[b] Items based on goal description feedback from qualitative research phase.

qualitative analysis, air pollution only appears in Table 1 as an item for SDG 13 climate action, even though it was also a theme for SDG 15 life on land, and SDG 7 affordable and clean energy. This avoidance of item duplication also explains why some goals only have two items each, such as SDG 1 no poverty and SDG 8 decent work and economic growth. Both of these goals were associated with poverty, the economy, and job opportunity by the qualitative research participants.

Furthermore, SDG 12 (responsible consumption and production) and SDG 16 (peace, justice and strong institutions) ended up with four and six questionnaire items respectively, as these goals were perceived to have numerous distinct themes. In addition, relating to overlapping items, while some items such as industry regulation and accountability in SDG 16 were also themes of SDG 12 (responsible consumption and production), as well as SDG 9 (industry, innovation and infrastructure), these items were allocated to SDG 16 as most mentions related to this goal.

3.3.2. *Questionnaire structure and importance scale*

To facilitate questionnaire completion and avoid respondent fatigue, the 50 SDG items were broken into six blocks of questions, which were rotated to avoid order bias (Serenko and Bontis, 2013). Respondents were asked to indicate their perceived importance of each item for achieving a sustainable future using a 7-point scale, as done in other sustainability studies where 1 = not at all important and 7 = essential (critical) (Greenland et al., 2022).

4. Results

Following data cleaning, the survey generated 472 responses. Pairwise deletion was applied to deal with missing values, which used all cases and segregated the variables where responses were recorded from the variables where responses were not recorded (i.e. missing data). Pairwise deletion is common where missing values are in the variables that have no dependency network with other variables of the dataset (Field, 2017).

4.1. *Respondent profile*

Survey respondent characteristics, as presented in Table 2, were reflective of the CDU student profile. In summary, 56.7% were under 34 years of age, and 66.7% were female. Overall, 64.0% were domestic students, and most (62.5%) had three years or more higher education experience.

4.2. *Exploratory factor analysis (EFA)*

As a data reduction technique that identifies core underlying dimensions (factors) and corresponding elements (Hair, 2010), exploratory factor analysis (EFA) was deemed as ideally suited for assessing SDG complexity. The EFA was conducted using principal component analysis with a Varimax rotation (Yong and Pearce, 2013). The Kaiser-Meyer-Olkin (KMO) measure (KMO = 0.951) indicated the adequacy of the sample of 472 responses for EFA, with Bartlett's test of sphericity ($p < 0.001$) indicating sufficient inter-item correlation and appropriateness to proceed with analysis of the factor structure (Yong and Pearce, 2013). The assessment of factors and the iterative process were based on factor and cross-loading criteria described in the literature (e.g. Nunnally, 1994), and items with factor loadings <0.4 and cross-loading differences <0.2 were sequentially removed from the analysis (Field, 2017).

The EFA generated a six-factor solution, comprised of 37 items. This solution was determined as robust, with a total explained variance of 74.3%, which was far greater than the acceptable level of 50% for social science studies (Hair, 2010). The factors were interpreted and named based on the items comprising each factor and in conjunction with the extant sustainable development literature. The factor structure and nomenclature are summarized in Table 3.

As shown in Table 3, Factor 1 (environmental protection) was the most important dimension for future sustainability and accounted for 48.847% of the total variance explained. This factor comprised all three items that represented SDG 13 (climate action) and the three items for SDG 15 (life on land). It also included two items from SDG 14 (life below water), as well as the sustainable water management practice item from SDG 6 (clean water and sanitation).

At 8.671% of variance explained, Factor 2 (social harmony and equality) was the next most substantial dimension perceived to determine future sustainability. This factor was clearly defined in terms of social harmony and equality, comprising the three items representing SDG 5 (gender equality) and two items for SDG 10 (reduced inequalities). It also comprised two of the five items from SDG 16 (peace, justice and strong institutions): fair laws and justice for all, and diversity and social harmony.

Factor 3 (sustainable production, industry and infrastructure) accounted for 5.964% of total variance explained. This comprised all three items that represented SDG 9 (industry, innovation and infrastructure), and two items for SDG 11 (sustainable cities and communities). The sustainable education item from SDG 4 (quality education) also loaded onto this factor, as did international support for sustainability in developing countries from SDG 17 (partnerships for the goals).

The fourth factor (sustainable consumption and socioeconomic behavior) comprised three of the four items that represented SDG 12 (responsible consumption and production), and one item each from SDG 3 (good health and well-being), SDG 7 (affordable and clean energy), and SDG 8 (decent work and economic growth).

Table 2
Demographic distribution of respondents (n = 472).

Variable	Category	Distribution (valid)		Missing values	
		Frequency	*Percentage*	*Frequency*	*Percentage*
Age	>18-24	70	14.8	2	0.4
	>24-34	198	41.9		
	>34-44	112	23.7		
	>44-54	63	13.3		
	Above 54	27	5.7		
Student status	Domestic	302	64.0	2	0.4
	International	168	35.6		
Gender	Male	150	31.8	7	1.5
	Female	315	66.7		
Total years in tertiary education	<1 year	52	11.0	3	0.6
	1–2 years	122	25.8		
	3 years or more	295	62.5		

Table 3
Factor loadings and measurement model properties.

SDG factor dimensions	Item (and corresponding SDG from qual. research)	Factor loading	Loading (HOC ≫ LOC)	Percentage variance	AVE	CR	α
1. Environmental protection	1. Reduced water pollution (14)	0.924	0.816	48.847	0.747	0.964	0.957
	2. Preserve ocean and biodiversity (14)	0.905					
	3. Preserve biodiversity and ecosystem on land (15)	0.894					
	4. Reduce air pollution (13)	0.880					
	5. Reduce deforestation and land degradation (15)	0.866					
	6. Reduce land pollution (15)	0.824					
	7. Combat climate change (13)	0.819					
	8. Reduce global warming (13)	0.811					
	9. Sustainable water management practice (6)	0.483					
2. Social harmony and equality	10. End racism and cultural inequality (10)	0.939	0.809	8.671	0.692	0.940	0.925
	11. End gender inequality (5)	0.784					
	12. Women empowerment (5)	0.781					
	13. End domestic violence (5)	0.763					
	14. Support disadvantaged and vulnerable (10)	0.748					
	15. Fair laws and justice for all (16)	0.584					
	16. Diversity and social harmony (16)	0.564					
3. Sustainable production, industry and infrastructure	17. Sustainable business and industry practices (9)	0.835	0.891	5.964	0.735	0.951	0.939
	18. Sustainable innovation for industry (9)	0.812					
	19. Sustainable infrastructure for business (9)	0.764					
	20. Smart cities (11)	0.704					
	21. Sustainable transport (11)	0.678					
	22. International support for sustainability in developing countries (17)	0.586					
	23. Sustainable education for all (4)	0.573					
4. Sustainable consumption and socioeconomic behavior	24. Recycling behavior (12)	0.793	0.834	5.064	0.687	0.929	0.908
	25. Energy-saving behavior (12)	0.732					
	26. Healthy lifestyle (3)	0.730					
	27. Affordable clean energy available to all (7)	0.693					
	28. Sustainable consumption behavior (12)	0.604					
	29. Sustainable economic growth (8)	0.599					
5. Sustainable governance, regulation and global relations	30. Accountable government and public institutions (16)	0.793	0.850	3.170	0.739	0.934	0.910
	31. Industry regulation and accountability (16)	0.753					
	32. Government sustainability policy (17)	0.639					
	33. Global peace (16)	0.634					
	34. Global partnership for sustainable development (17)	0.623					
6. Acute poverty reduction	35. End hunger everywhere (2)	0.939	0.645	2.591	0.768	0.908	0.848
	36. End poverty everywhere (1)	0.788					
	37. Enough resources for necessities (1)	0.739					
KMO value			0.951				
Bartlett's test			0.000				
Total percentage variance explained			74.307				

Note: Principal component analysis conducted with Promax rotation; AVE = average variance explained; CR = composite reliabilities.

The fifth factor (sustainable governance, regulation and global relations) comprised three of the five items making up SDG 16 (peace, justice and strong institutions), and two of the three items for SDG 17 (partnerships for the goals).

The final factor (acute poverty reduction) comprised both the items of SDG 1 (no poverty), as well as end hunger everywhere from SDG 2 (zero hunger).

4.3. Hierarchical components model and dimensionality assessment

Following EFA, a hierarchical component model (HCM) was produced using partial least square structural equation modeling (PLS-SEM) via the SmartPLS v.4.0 program. PL-SEM facilitates estimation of complex models and accommodates for distributional violations, providing a high degree of statistical power (Hair et al., 2019). The HCM was used to clarify the importance of each SDG factor generated during EFA, and to facilitate reliability and validity assessment.

4.3.1. Reliability and validity assessment

Construct reliability relates to the capacity of an instrument to continually measure the intended concept and yield matching results (Nunnally, 1994). Validity relates to the instrument's ability to measure what it is meant to measure (Clark and Watson, 1995). The results reported in Tables 3 and 4 confirm the reliability of the six SDG dimensions (α: 0.848–0.957; CR: 0.908–0.964), and that the constructs are valid in the measurement of respective SDG dimensions (AVEs: 0.687–0.747; HTMT0.85.0.443–0.819) (Hamid et al., 2017).

4.3.2. Dimensionality assessment and modeling

An important objective of this study was to explore an SDG typology or model based on student perceptions. After confirmatory tetrad analysis (CTA) developed in SmartPLS, a reflective-reflective higher-order model of the SDGs perceptions was produced (Gudergan et al., 2008) comprised of the six distinct but intercorrelated SDGs dimensions (see Fig. 3). In order of importance (according to factor loadings), these were sustainable production, industry and infrastructure ($\lambda = 0.891$); sustainable governance, regulations, and global relations ($\lambda = 0.850$); sustainable consumption, and socioeconomic behavior ($\lambda = 0.834$); environmental protection ($\lambda = 0.816$); social harmony and equality ($\lambda = 0.809$); and acute poverty reduction ($\lambda = 0.645$).

Table 4
Discriminant validity of constructs using $HTMT_{0.85}$.

Variables	A	B	C	D	E	F
A. Sustainable production, industry and infrastructure	***0.857***					
B. Acute poverty reduction	0.540	***0.876***				
C. Environmental protection	0.660	0.443	***0.864***			
D. Sustainable governance, regulations, and global relations	0.819	0.518	0.675	***0.860***		
E. Social harmony and equality	0.689	0.681	0.544	0.731	***0.831***	
F. Sustainable consumption, and socioeconomic behavior	0.814	0.652	0.634	0.665	0.628	***0.829***

Note: Elements on diagonal (bold and italic) are the square root of AVEs. All other elements are $HTMT_{0.85}$ correlations.

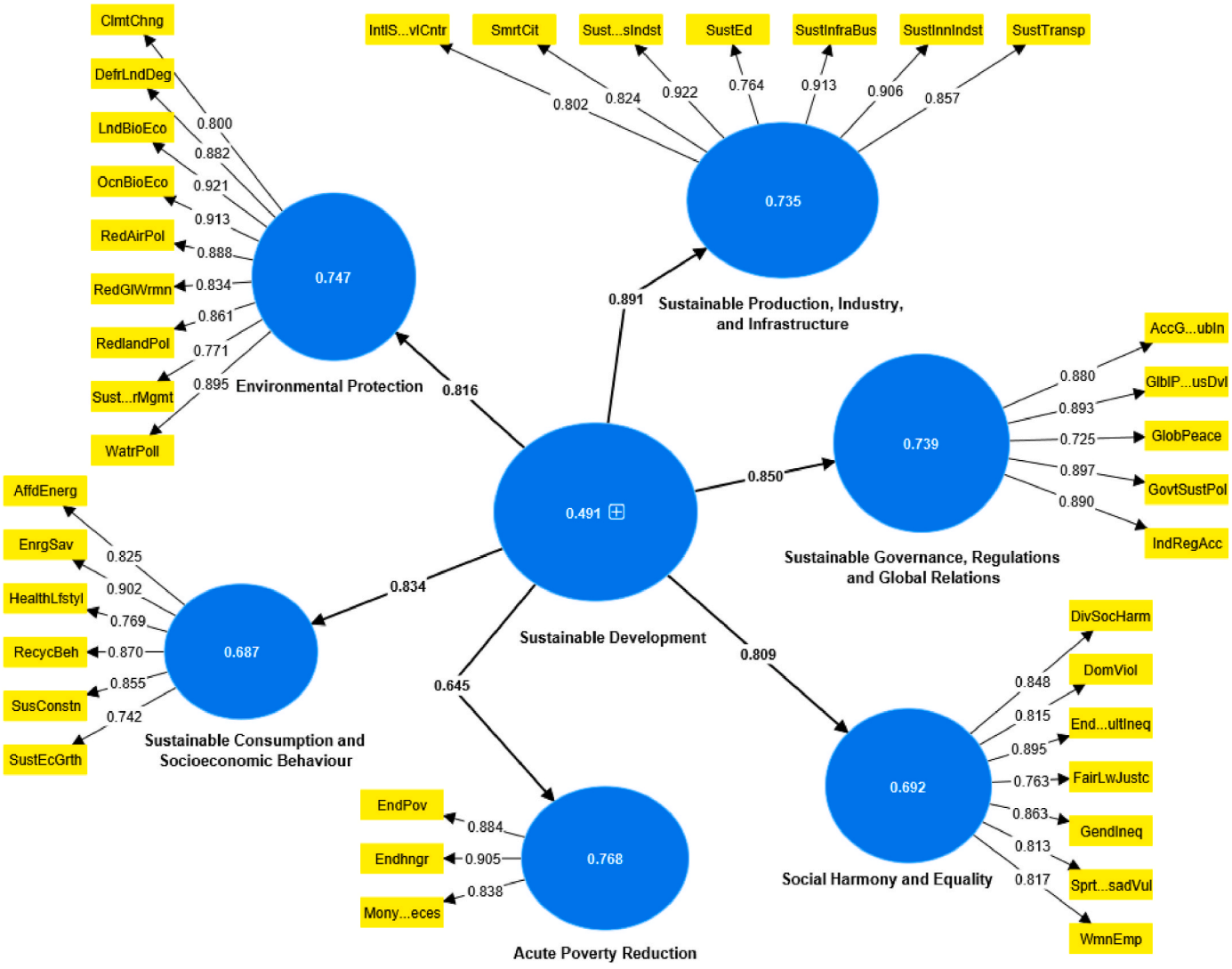

Fig. 3. HCM model of student SDG perceptions.

5. Discussion and conclusion

The EFA of the importance ratings of the SDG themes produced a logical empirical six-dimensional model of sustainable development made up of 37 SDG items. The 74.3% of variance explained by the model was high, indicating that the model is a reliable representation of the importance of SDGs for sustainable development.

Fig. 4 presents a simplified model of the SDG-based sustainability dimensions affecting sustainable development, based on the EFA and SmartPLS analysis. In this visualization, SDG tile size reflects how many items for each SDG loaded onto each factor. This model provides a framework that can help to make empirically informed decisions of where to place and prioritize SDGs in terms of core sustainability dimensions.

In comparison with traditional pillar-based models of sustainable development, the framework in Fig. 4 further validates environment as a distinct component. For example, the environmental protection factor provides statistical validity to the four SDGs (13 climate action, 14 life below water, 15 life on land, 6 clean water and sanitation) that Rockström and Sukhdev (2016) included in the environmental (biosphere) layer in their conceptual sustainability model.

The governance or political pillar often reported in four-pillar

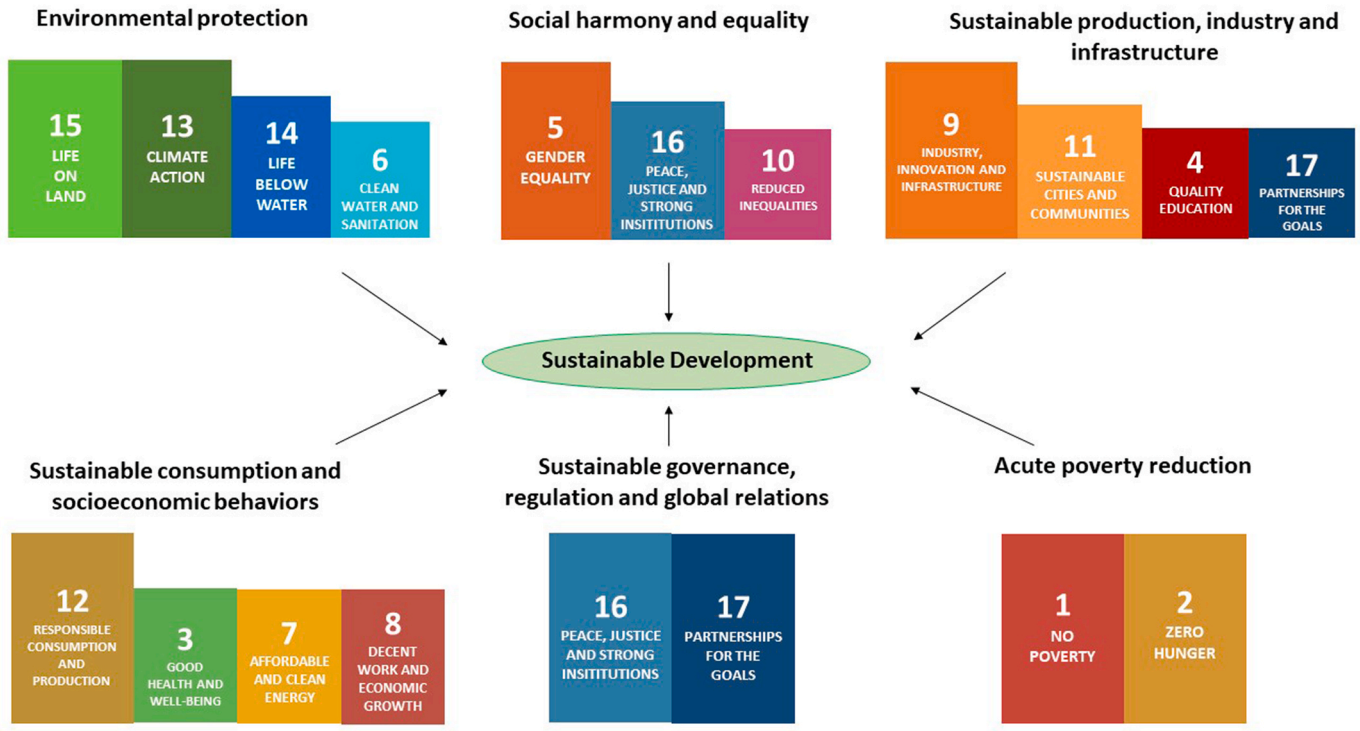

Fig. 4. Six-dimensional empirically derived SDG model.

models (e.g. Zhang, 2013) is also evident as a distinct factor in the new empirical model (i.e. the sustainable governance, regulation and global relations dimension). This factor combined most of the items representing SDG 16 (peace, justice and strong institutions) and SDG 17 (partnerships for the goals). The EFA deepens understanding of this governance sustainability pillar, particularly in the context of the importance of effective industry regulation and accountability, as well as peaceful global relationships.

While the social sustainability pillar is also evident, unlike earlier models that present it as a distinct dimension (e.g. Greenland et al., 2022; Rockström and Sukhdev, 2016), it appears across two dimensions in the new model. The social harmony and equality dimension is comprised of SDG 5 (gender equality) and SDG 10 (reduced inequalities), as well as the fair laws and equal justice, and the diversity and social harmony items of SDG 16 (peace, justice and strong institutions). The sustainable consumption and socioeconomic behaviors dimension is also society-related and made up of items from SDGs 12 (responsible consumption and production), 3 (good health and well-being), 8 (decent work and economic growth) and 7 (affordable and clean energy), which reflect the features of a society required for a sustainable future.

As with society, the economic pillar of sustainability did not emerge as a single dimension in the new model; it was divided across two. Sustainable production, industry and infrastructure appear as a key economic dimension, comprised of SDGs 9 (industry, innovation and infrastructure) and 11 (sustainable cities and communities). Two items with infrastructure-related themes from SDGs 4 (quality education) and 17 (partnerships for the goals) also made up this dimension. The inclusion of the SDG 17 item international support for sustainability in developing countries is likely due to the support often provided to emerging markets in the form of infrastructure development and education (e.g. Abbas et al., 2021). In addition, the inclusion of the SDG 4 item sustainable education for all echoes the literature, where the importance of education for building organizational competencies in CSR and sustainable business practices has been highlighted (e.g. Kolb et al., 2017).

The new model's acute poverty reduction dimension, comprising SDG 1 (no poverty) and SDG 2 (zero hunger) also has clear economic underpinnings. Its emergence as a distinct factor provides empirical support to the observations of others about the significance of extreme poverty, and the fact that the importance of other SDGs is reduced when people are trying to survive on a daily basis (e.g. UNESCO, 2020).

In conclusion, SDG complexity presents environmental management educators wishing to promote sustainable development with numerous challenges, especially in relation to overlapping social and economic goals that often conflict with environmental goals. While former sustainability models have attempted to reduce this complexity, they have often been conceptual in nature and/or have involved the subjective classification of SDGs. This study's mixed-method approach used perceived SDG importance as well as EFA to generate a robust six-dimensional model of factors that determine sustainable development. It validates aspects of some traditional pillar-based models, in terms of empirically identifying the SDGs that make up environment and governance dimensions. It also provides new, more detailed insights in terms of social and economic sustainable development. For example, it identifies SDGs that relate to distinct social dimensions of social harmony and equality, and sustainable consumption and socioeconomic behaviors. In relation to economic dimensions, associated SDGs in the new model are related in terms of sustainable production, industry and infrastructure, and acute poverty reduction. This new empirical model can subsequently assist in overcoming SDG complexity, including subjectivity, to help educators and thereby citizens and organizations to categorize the goals more reliably, as well as appreciate their key dimensions and impacts. This research can therefore support the development of more comprehensive environmental management education programs that effectively integrate environmental, social, and economic themes and interactions, which is necessary to facilitate future sustainable development (e.g. de Andrade Guerra et al., 2018; Obrecht et al., 2022).

In terms of study limitations, this research was conducted in Australia with a sample predominantly comprised of domestic university students from one faculty, which may impact on the generalizability

of the findings. Further research is required to understand student perceptions in other education contexts, such as vocational education, and across a wider range of disciplines such as public health. Furthermore, other stakeholders such as organizations and government agencies may have different sustainability perspectives.

Given the contextual country-specific nature of sustainable development challenges observed by other researchers (e.g. Tonegawa, 2023), further research is also required to test the applicability of this new model in other countries. For example, while quality education and healthcare, the provision of which is ubiquitous in Australia, did not emerge as distinct SDG dimensions, this may not be the case in some emerging markets. Furthermore, while environmental protection in this study's factor analysis accounted for 48.8% of the variance explained, its relevance may not be as strong in less developed countries. In addition, while acute poverty reduction emerged as a significant factor in this study, its relative importance in terms of variance explained was low. This may also not be applicable in emerging markets, where larger populations often face daily survival challenges that are likely to reduce the prioritization of other SDGs (e.g. UNESCO, 2020). Multi-country studies therefore warrant future research attention, to investigate the contextual differences of SDG dimensions. Such investigation could also examine the interrelationships between core SDG dimensions, such as the extent that acute poverty moderates the perceived importance of other goals.

Credit author statement

Steven Greenland: Conceptualization, Methodology, Writing - Original Draft Preparation, Writing - Review & Editing. **Muhammad Saleem**: Conceptualization, Methodology, Investigation, Writing - Original Draft. **Roopali Misra**: Investigation, Visualization, Writing - Original Draft. **Ninh Nguyen**: Investigation, Writing - Review & Editing. **Jon Mason**: Investigation, Writing - Original Draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgment

The research was funded by CDU's Office of Research and Innovation, and supported by the Chamber of Commerce, Northern Territory. The authors would like to thank all project team members and acknowledge input to the original research proposal by Dr Ulrike Kachel, as well as editing of the final journal manuscript by Jeanette Walton of Walton's Words.

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