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Conceptual Model of Technical Sustainability for Integration Into Electrical/Electronic Engineering Programmes in Nigerian Polytechnics

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ABSTRACT Global warming is probably the greatest threat of this century. Several developed and developing countries have taken important measures to reduce its adverse effects, including greening their Higher Education Institutions (HEIs) curricula. However, Sub Saharan African countries are left behind to that effect, despite the fact that people in these countries are the greatest recipients of the global warming harmful consequences. The goal of this research therefore, is to investigate the suitable competencies in technical sustainability for incorporation into Higher National Diploma electrical/electronic engineering curriculum in Nigeria. The authors used mixed-method approach employing sequential exploratory design in the study. In the qualitative phase, we analyzed documents consisting of 10 journal articles and 3 skills standards, as well as conducted a total of 10 interviews with experts. Also, we carried out 3 rounds of modified Delphi survey using 28 participants to ascertain the appropriateness of the competencies suitable for infusion into the said curriculum. The study discovered competencies suitable for incorporation into the curriculum which include cognitive-related competencies in clean energy, eco-design, and R&D; psychomotor-related competencies in sustainable production, waste-to-energy-technology, communication/ICT, and use of modern engineering software tools; and affective values related to engineering ethical responsibility, occupational health and safety, cooperation/teamwork, and equity. We analyzed only 13 documents, conducted 10 interviews, and administered questionnaires in 3 rounds of Delphi survey technique to 28 experts in only one geo-political zone of the country. Thus, conclusions derived from these sources rely on the genuineness of the information provided by the participants. The findings provided the researchers, accreditation bodies as well as curriculum developers with competencies in technical sustainability in the events of curriculum upgrade or renewal to integrate technical sustainability. The findings are the results of triangulated data elicited theoretically and empirically.

INDEX TERMS Technical sustainability, electrical/electronic engineering, sustainability integration.

I. INTRODUCTION

Global warming and its effects are no longer an allegory as perceived by many, since it has plunged humanity in to an entangled crisis of environmental, social and economic systems. Many people refer to it as greenhouse effects, while others, in a broader notion, call it sustainability problems or challenges. Unintentional consequences due to new human behavioral paradigms about standard of living have triggered the challenge for society to maintain itself throughout generations, the so called 'sustainability challenge'. This, therefore, calls the need for all the people in the planet to be true stakeholders in adequately addressing the menace. As a result, the World Commission of Environment and Development (WCED) (1987), proffer a viable solution to these problems, which it termed as 'sustainable development. The commission defined sustainable development as 'development that meets the needs of the present without

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comprising the ability of the future generations to meet their own needs'. Moreover, the commission made emphasis on education as a critical tool for promoting the sustainable development and improving the capacity of people to address sustainability problems[44]; [19]. This consequently led the UN to declare 2005-2014 as the 'UN decade for education for sustainable development' (DESD). The main object for this decade was to incorporate the philosophies, ideals and practices of sustainable development into all features of education and learning (UNESCO, 2005 p.5). The UN further define the ESD as 'education that promotes transformation of manners that will build a better sustainable potential in terms of environmental uprightness, economic feasibility, and a fair society for present and future generations' (UNESCO, 2002). As a result, higher education institutions were appealed to build systems for environmental and development education, provides cross-disciplinary courses to all students, elevate quality and superiorities in interdisciplinary research and education, and contribute more to developing of responsiveness for all stakeholders, not just students and faculty within the academy (UNESCO, 1992, p.322-5). Additionally, the 2030 Agenda for Sustainable Development recognizes the critical role of education in reaching sustainability goals, calling on all countries "to ensure, by 2030, that all learners acquire the knowledge and skills needed to promote sustainable development, (Incheon Declaration and Framework for Action, 2015, p. 20). Adequate competencies (knowledge, skills and attitudes) in technical sustainability will go a long way in enhancing engineering graduates' understanding of technical aspects of life. This understanding will help them deal adequately with the future sustainability challenges in the workplace and in the broader society. Thus, the chief objective of the study is to develop a conceptual model of technical sustainability suitable for incorporation into HND electrical/electronic engineering curriculum in Nigeria.

II. THEORETICAL FRAMEWORK

The theoretical framework of the study is designed to focus on the discussion of study variables, including the concepts of sustainable development and sustainability, the pillars of sustainability, the emergence and relevance of technical sustainability, the electrical/electronic engineering programme in Nigerian polytechnics, and the conceptual model of the study.

A. THE CONCEPTS OF SUSTAINABLE DEVELOPMENT AND SUSTAINABILITY

Sustainable development is viewed as a pathway to promote the lives of the people in a way that the natural resources they rely on are sustained. Its first definition surfaced in World Commission on Environment and Development (WCED, 1987) report also known as Bruntdland Report, as "development that meet the needs of the present without compromising the ability of future generations to meet their own needs" (p.43). Analyzing this definition, [41] deduced that sustainable development is founded on the concepts of development, needs, and future generations. For the academic community, the Bruntdland's definition of sustainable development serves as a basis for the emergence of several definitions to suit the needs and objectives of many disciplines. Reference [27] identified more than 300 definitions and interpretations of the concept of sustainable development which largely follow the core of the concept. Furthermore, sustainable development was also founded on three-pillar concept, often known as triple bottom line concept [30]. This includes the environment, the economy and the society, which are viewed as interwoven. Absolute sustainable development is expected to be realized through a balance among the three pillars.

The term 'sustainability' on the other hand, does not have a precise and generally established definition by all sectors and society [6]. Even though widely discussed and agreed by common sense, the concept of sustainability, since it lacks accuracy, ends up gaining numerous senses, sometimes paradoxical. The term's ambiguity makes it possible to be used in various discourses and actions, such as in different political and economic interest. Nevertheless, [29] refers to sustainability as a state or condition that can be maintained over an indefinite period of time. Likewise, [6] after analyzing several definitions, see sustainability as 'a goal to be achieved and also a process to reach the goal' (p.6). This form of goal and process differ according to socioeconomic and environmental contexts. Furthermore, [39] stated that it is a notion, a practice and an all-embracing goal that preferably permits to deal with existing circumstances of intertwined environmental, economic and social crises considered collectively as 'global change'.

As such the goal of sustainability is delightfully diverse, safe, healthy, and just world, with clean air, soil, water and power, economically, equitably, ecologically and elegantly enjoyed [14]. Sustainability is to found the means of production, distribution, and consumption of existing resources in a more cohesive, economically efficient and ecologically viable way. Reference [17] argued that future sustainability of human society relies on the capacity and enthusiasm of people to align their behavior and institutions to sustaining ecological sincerity in human relationships with earth. Therefore, a conversant and coherent concept of sustainability is required to be diffused in to the cultural, moral and educational philosophies of human society, which should be applied decisively to concepts of growth, development, and the environment.

B. THE PILLARS OF SUSTAINABILITY

Most definitions of sustainability encompass the idea that there are three interdependent pillars: environmental, economic and social. These are usually presented as three interlocking circles or as independent columns (pillars) supporting sustainability [32] and [37]. If one or more of the pillars of sustainability are neglected then the foundation will not support the generations of the future. The objective of sustainability according to this model, is to maximize the goals across all three systems, and is illustrated by the intersection of these circles. Critically, the model encompasses the understanding that each of the system goals is socially constructed and that achieving sustainability requires trade-offs; choices have to be made at particular points in time and at particular scales as to what is being pursued and how, and sustainability requires recognition of the costs involved for particular interests and for groups of people. The three pillars basic model is also refer to 'Triple bottom line' (TBL) model of sustainability [30]. It is seen as the predominant model in which environment, social and financial outcome are taken into account.

1) ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability refers to sustaining the quality of the environment required for economic activities and quality of life. This includes environmental protection, reduced emission of GHG, rational use of resources etc. Reference [21] stated that environmental sustainability concentrates on general vitality and health of ecosystem in order to secure balanced nature, elasticity of ecosystems at a global level and their ability to adapt to changes in biosphere, as well as ability to secure future possibilities.

2) ECONOMIC SUSTAINABILITY

Economic sustainability is about sustaining the natural, social and human capital required to achieve income and living standard. It seeks to maximize the flow of income and consumption that could be generated while at least maintaining the stock of assets or capital which yielded beneficial output [21].

3) SOCIAL SUSTAINABILITY

Social sustainability refers to the preservation of society and cultural identity, respect of cultural diversity, race, religion, and preservation of social values, rules and norms, protection of human rights and equality. Reference [21] stated that social sustainability reflects the interface between development and dominating social norms and strives to maintain the stability of social sustainability. It seeks to minimize vulnerability and maintain the health of social and cultural systems and their ability to withstand shocks [58].

C. THE EMERGENCE AND RELEVANCE OF TECHNICAL SUSTAINABILITY

Sustainability has been defined in many ways, and is often considered to have three distinct components as described above. Many scholars have challenged the incompleteness and incomprehensiveness of the definition of sustainable development as provided in the Brundtland Report [54], [47], [63], [56], and [61]. These scholars particularly claimed that an important pillar has been missed in the description and framework of sustainable development. This missing pillar is 'technical sustainability'. Although technical sustainability is not one of the original three components of sustainability cited above, it is indirectly linked to each [60]. For instance, technical/engineering processes uses resources to drive much if not most of the world's economic activity, in virtually all economic sectors, e.g., industry, transportation, residential, commercial, etc. Also, resources used in technical/engineering, whether fuels, minerals or water, are obtained from the environment, and wastes from engineering processes (production, transport, storage, utilization) are typically released to the environment. Finally, the services provided by technical/engineering allow for good living standards, and often support social stability as well as cultural and social development. Given the intimate ties between engineering and the key components of sustainability, it is evident that the attainment of sustainability in technical/engineering is a critical aspect of achieving sustainable development, in individual countries and globally [60].

Engineering is an innovative, resourceful and integrated discipline; however it is only in the last two decades that there has been prevalent understanding of the philosophical and emergent effect engineering has on all sectors of society. Reference [60] asserts that a sound technical basis of sustainability helps avoid confusion regarding engineering issues. Technical sustainability concentrates on a broad range of mechanical and technical issues that establishes the design and manufacture of products [54]. These include the scientific research and appropriate technology corroborating product design, function and development; ease and efficiency of durable construction and use; maintenance and functioning capabilities that meets the objectives for which the product is designed; material selection and reduction, recovery, reuse or disposal of parts of unused materials [47]. Technical sustainability thinking encourages manufacturing processes and industrial practices that are less insidious or destructive to environmental, social or economic contexts, and bears preferably, neutral or positive effects on these contexts. To this end, HND electrical/electronic engineering graduates should learn that a design must meet the technical requirements of the products or processes under deliberation.

D. HIGHER NATIONAL DIPLOMA ELECTRICAL/ELECTRONIC ENGINEERING PROGRAMME IN NIGERIA

Growing concerns about the humans' negative impacts on our planet, and the implications of those impacts for future generations, have led many to argue that higher education has a key role to play in helping us move to a future characterized by an ability to meet the needs of the present without impeding the ability of future generations to meet their own needs. The fundamental problem we are facing in meeting the goal of education for a healthy and sustainable society for all students is that the existing curriculum in higher education has not been developed to examine how we shape a sustainable world [26], [40], [54]. Much of the curriculum has been developed to provide students with an increasingly narrow understanding of disciplines, professions and jobs and is focused on specific knowledge and skills employed in the given area [45]. What is needed is a curriculum that prepares learners for living sustainably, both professionally and personally, and that explicitly helps the learner deeply understand the interactions, inter-connections, and the consequences of actions and decisions. Regardless of the subject of the curriculum, students must learn and practice holistic systems thinking and be able to apply such thinking to real world situations [13] and [20].

The HND electrical/electronic engineering programme in Nigeria is designed to impart on students specialized and useable skills in this field of engineering. There are three options currently available in the programme, whereby a student is required to specialize in one: Electronics and Telecommunications, Electrical Power and Machines, and Instrumentation and Control. In Nigeria, electrical/electronic engineering programme in the polytechnics is one of the sources through which industries get steady supply of trained manpower. Trained electrical engineers grounded in key generic skills are inevitable for the sustained development of industries. But one thing that is glaring in Nigeria presently is the dearth of effective technical manpower required in all the sectors of environmental, economic, and social life [50]. This is perhaps as a result of lack of proper incorporation of elements of sustainability in to the curriculum.

Reorienting HND electrical/electronic engineering curriculum by inclusion of technical sustainability competencies encompasses a vision for society that is not only ecologically sustainable but also one which is socially, economically and politically sustainable as well. In a sustainable curriculum, students must understand how the systems of which they are a part of function. In order to accomplish this, we need a significant segment of the learning opportunities for students to be structured to accomplish these outcomes. To do so will require significant changes in the curriculum, and the pedagogies used to deliver that curriculum. These changes will only occur when large numbers of faculty have the knowledge, skills, resources, support, incentives, and disposition to change what and how they teach.

Reference [48] summarizes six broad strategies for incorporating principles of sustainability into curricula. The first is to create an organization-wide assessment rubric targeting a green outcome. The second strategy discusses development of a new green program. Thirdly, a green program outcome can be added to an existing program. Strategy four is to create a course to augment an existing program or use as a stand-alone offering. The fifth strategy is to analyze course level competencies and build learning modules for green competencies. Finally, performance standards for competency assessment can be modified to incorporate sustainability into courses. This study focuses on development of a model of technical sustainability for incorporation into HND electrical/electronic engineering curriculum. The model will emerge from the competencies (knowledge, skills and attitudes) in technical sustainability.

E. THE CONCEPTUAL FRAMEWORK OF THE STUDY

Conceptual framework in a research is an important component of the study which consists of concepts that are placed within a logical and sequential design. It is the researcher's own position on the problem and gives direction to the study. It shows also, the relationships of the different constructs to be investigated in the study. The review of related literatures provided the researcher with the premise to come up with and designed the conceptual framework of this study. The literature revealed that sustainability was a three-legged concept including environment, economic and social contexts. But lately, scholars such as [54] and [55] strongly advocated for another dimension of sustainability which they referred to as ''technical sustainability''. It is believed that higher education programmes are always in constant need to be updated to cater for inclusion of new developments, knowledge and skills as a result of advances in industries and businesses, which are dynamic organizations whose ever-changing needs of technology, machines, materials, products and processes cannot be over emphasized [46]. This is particularly so in engineering education programmes as dynamism is one cardinal characteristics of the profession.

In this study, competencies (knowledge, skills and attitudes/values) in the technical context of sustainability were first explored qualitatively through document analyses which were later corroborated with interview using the small sample of the population. Furthermore, the researchers later employed the use of three-rounds of Delphi survey technique, using wider sample of the population, to re-ascertain the suitability of the competencies for incorporation in to the curriculum. The conceptual framework of the study is shown below in figure 1.

III. RESEARCH METHODOLOGY

The authors employed mixed-method study adopting sequential exploratory design in carrying out this research. The researchers collected data firstly through documents analysis and interviews with smaller sample of the population; and secondly, using survey through three-rounds modified Delphi technique. We carried out the study in the North-Western Nigeria that comprises of 274 registered electrical/electronic engineering experts as target population of the study. These experts are distributed in 10 polytechnics and 36 manufacturing industries. In the qualitative phase, 13 documents (10 journal articles and 3 skills standards) that mainly discussed technical sustainability competency development were analyzed, while 10 participants (6 and 4 experts from academia and industry respectively) were selected through quota sampling procedure for interviewing. In an effort to validate the findings of the qualitative study, the researchers triangulate the qualitative findings with a quantitative study conducted by means of three-rounds of Delphi survey with respondents in academia and industry. We used purposive sampling to select 28 experts (18 lecturers and 10 industrial personnel) in the study area to participate in the survey.

Five (5) experts validated the interview protocol and subsequently the round 2 questionnaire by checking the face and content validation. The reliability of the instrument was established via pilot test. The researchers administered the

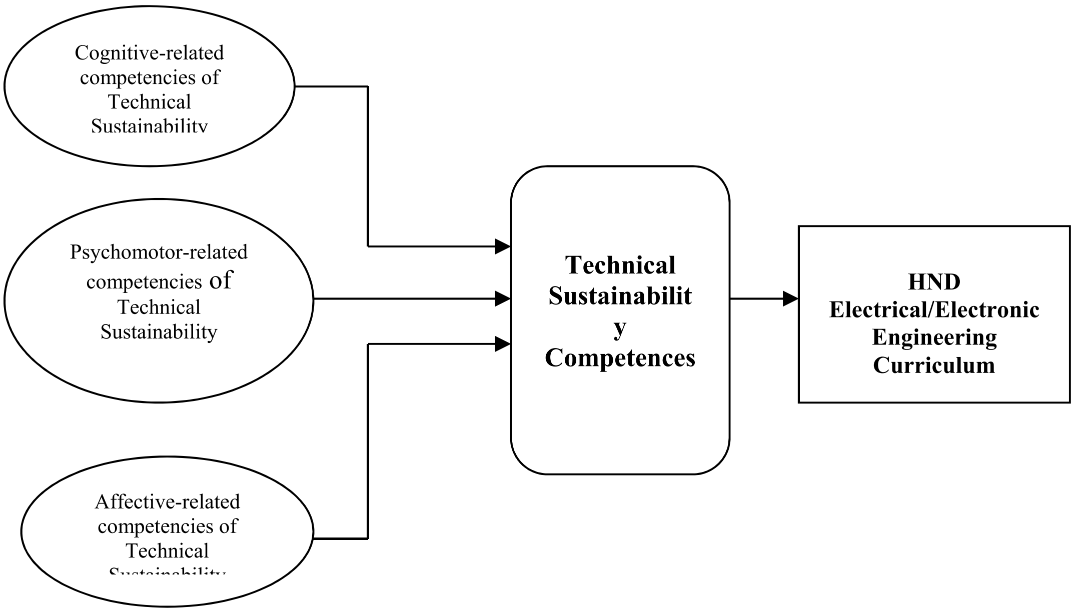

FIGURE 1. Conceptual research framework (Adopted from Besong and Holland, 2015).

round 2 questionnaire to 9 experts in academia and industry in Bauchi state, Nigeria (not part of the study area). Research instrument's reliability was computed with the aid of SPSS statistical software version 20, using cronbach's Alpha method to ascertain the extent of the homogeneity of the items. The results obtained shows that the reliability coefficients for the sub-sections B – D were 0.946, 0.956 and 0.846 respectively. On the whole, the reliability coefficient of the entire questionnaire is 0.976 which indicates that the items in the questionnaire were internally consistent in measuring what was intended to be measured for the study.

IV. DATA ANALYSIS AND RESULTS

This section presents the findings of the study, and is organized and presented in to findings of qualitative phase and findings of quantitative phase as follows.

A. RESULTS OF DOCUMENT ANALYSIS

Documents analyzed to identify competencies that are relevant for attaining technical sustainability and are suitable for incorporation into HND electrical/electronic engineering curriculum, were separated in to Journal Articles and Skills Standards. The journal articles are listed below: [8], [10], [13], [24], [42], [49], [51], [52], [64], and [65]. The three (3) technical sustainability competency standards analyzed are: Green/Sustainability knowledge and skill statements standards: US National Career Clusters Framework, Wisconsin Standard for Technology & Engineering, and Sustainability and Engineering in New Zealand – Practical guidelines for Engineers. We analyzed the documents in order to identify the competencies, however, because the competencies are so profuse, thematic analysis were conducted to come up with categories under which all the competencies were grouped as shown in the table 1 below.

Table 1 shows the various categories of competencies in technical sustainability as a result of analysis of some relevant documents. It is vital to stress here that the researchers identified numerous competencies which seems to be impracticable to be reported here, and therefore thematic analysis was employed to classify the competencies into categories that include: life cycle engineering, eco-design, cleaner production, engineering ethics, policies and decisions, emerging technologies/innovations, ICT/E-learning technologies, and modeling, simulation and optimization.

B. RESULTS OF INTERVIEW

The data collected from the interviewees were analyzed with the help of Nvivo 11 to facilitate the organization and transformation of the data in to meaningful and expedient information. Thematic analysis style was used on the data, and three themes became apparent supported by the three domains of learning, consisting of cognitive, psychomotor and affective spheres. In the course of analyzing each realm, other subthemes emanated as follows: Subthemes that emerged from the cognitive realm are energy generation, transmission and distribution; cleaner production and LCE; STEM and HOTS; ICT and E-learning technologies; and engineering management. While subthemes that include practical technical skills; sustainable design and production; and inventions and innovations using local contents emerged in the psychomotor sphere. Eventually, all the competencies analyzed under affective domain were classified under ethical awareness as a subtheme. Table 2 summarized the study findings as shown below.

TABLE 1. Findings matrix from documents analysis on competencies in technical sustainability.

Journal Articles	LCE	ED	CP	EPD	ETI	ICT/ELT	MSO
Batterman, et al., (2011)	√	√		√		√	√
Noe, Pozzi & Magni (2015)	√	√		√	√	√	
Siew (2014)				√			
Besong & Holland (2015)			√				
Boutin & Chinien (2008)				√		√	
Dancz, et al., (2016)	√			√	√		
Lindow, Woll and Stark (2012)	√	√					
Sproule & Van Ryneveld, (2009)				√	√	√	
Olinzock, et al., (0215)	√						
O'Rafferty, Curtis, and O'Connor, (2014)	√	√	√	√	√	√	√
Skills Standards							
Skills Standard 1		√	√			√	√
Skills Standard 2	√	√			√	√	√
Skill Standard 3	√	√	√	√	√		

KEY:
Journal Articles: LCE - Life-Cycle Engineering; ED - Eco-Design; CP - Cleaner Production; EPD - Engineering Ethics, Policies & Decisions; ETI - Emerging Technologies/Innovation; ICT/ELT - ICT/E-Learning Technologies; MSO - Modeling, Simulation & Optimization
Skills Standards
Skills Standards 1: Green/Sustainability knowledge and skill statements standards: US National Career Clusters Framework
Skills Standards 2: Wisconsin Standard for Technology and Engineering
Skills Standards 3: Sustainability and Engineering in New Zealand – Practical guidelines for Engineers

The findings of the study as shown in table 2 unveils that technical sustainability is regarded as an imperative pillar, and is becoming an essential one in issues related to sustainability. The findings also affirmed that technical sustainability is critical for engineering graduates to be able to meaningfully contribute their quota for achieving sustainable development goals. Several competencies in technical sustainability were proposed by the research participants that cut across all domains of learning, and this confirmed that the inclusion of competencies in technical sustainability into the HND electrical/electronic engineering curriculum cannot be overstressed.

C. RESULTS OF QUANTITATIVE PHASE

The quantitative findings of the study were developed from the Delphi survey data using descriptive and inferential statistics as well as exploratory factor analysis. The findings of these two methods generated three (3), four (4), and one (1) clusters for cognitive-related, psychomotor-related, and affective-related technical sustainability competencies respectively.

1) DESCRIPTIVE STATISTICS

Data for the analysis using descriptive statistics were collected through three rounds of modified Delphi technique. In round 1 of the Delphi survey, list of competencies in technical sustainability that were gathered through qualitative study (document analysis and interview) formed the first round of the Delphi survey. We listed the competencies based on the emerged subthemes from the qualitative study, comprising cognitive-related, psychomotor-related and affective-related competencies in technical sustainability. The objectives of Round 1 Delphi survey include making the participants become familiar with the competencies in technical sustainability as entrenched theoretically through documents analysis, and empirically through semi-structured interviews with experts. Also, to request the participants to edit, modify or suggest new sustainability competencies that are important for inclusion in the Delphi round 2.

The analysis of Round 1 was carried out qualitatively using thematic analysis. A lot of the competencies were edited based on grammatical structures, while some of the competencies were modified to suit the objectives of the study. The participants suggested for shifting of some of the competencies from one subtheme to another. Suggestions made by more than 75% of the participants were considered. No competency under any subtheme whatsoever was unanimously agreed by 75% of the participants to be completely removed from the list. However, the participants suggested a lot of new competencies. We compiled all the new competencies under their appropriate subthemes. After carefully studying these new competencies, we classified them into three categories, viz; (a) those that were completely accepted for inclusion, (b) those that makes meaning but the researchers needs more information from those participants that proposed them and (c) those that were out rightly rejected.

TABLE 2. Interview findings on competencies in technical sustainability.

Competencies Proposed by the Participants	Respondents	Subthemes
Cognitive Competencies *the learning of science, technology, engineering and mathematics (STEM), at all levels;* *development of higher order skills which are necessary to modernize and revive local industry;* *ICT and e-learning technologies; green technology;* *knowledge of MATLAB, E-TAB and other relevant softwares;* *hands-on skills of using lathe machines, TLC and CNC machines;* *an understanding of energy scarcity;* *understanding of how local resources are used to make products which*	EEL1, EEL 2, EEL 3, EEL 4, EEL 5,	Energy Generation, Transmission & Distribution Cleaner Production & LCE
meet local people's needs and the needs of people in other places; *understanding that resources from other places may be used to make products locally to meet their needs;* *understanding of consumer behavior and household energy consumption;* *knowledge of technical, economic, and environmental factors associated with fossil and nuclear fuels;* *knowledge of technical, economic, and environmental factors associated with renewable energy including bio-fuels, wind, wave, tidal and solar energy;* *knowledge of technical, economic, and environmental factors associated with opportunities and energy potentials;*	EEL 6, CEO, OM, SE, TEC	STEM & HOTS ICT & E-Learning Technologies Engineering Management
Psychomotor Competencies *the acquisition of practical electrical engineering skills;* *integrating local contents in to engineering practices;* *technological innovation;* *ICT mediated and digital approaches of learning;* *system modeling-simulation and actualizing;* *development in robotics;* *expertise in solar and wind energy and maintenance and repairs of electrical/electronic artifacts;* *solar installation, satellite installation and electrical installation and GSM repairs;* *software design and computer maintenance and repairs;* *hands-on skills of using lathe machines, TLC and CNC machines;* *ability to design, develop and assess electrical/electronic projects based on the environmental indicators;* *Knowledge of case studies of energy successes and failures;* *able to effectively operate various types of machines such as CNC;*	EEL1, EEL 2, EEL 3, EEL 4, EEL 5, EEL 6, CEO, OM, SE, TEC	Practical Technical Skills Sustainable Design and Production Inventions and Innovations using Local Contents
Attitudes *the acquisition of right attitudes;* *ethics of engineering profession;* *exploring what it means to be an ethical producer;* knowledge of decision support/operations research/systems analysis; solve decision problems, decision support techniques;	EEL1, EEL 2, EEL 3, EEL 5, EEL 6, CEO, SE, TEC	Ethical Awareness

All necessary corrections, modifications and suggestions proposed by the Delphi participants in round 1 were finally effected, and this results in a comprehensive list of the competencies. In Round 2 of the Delphi survey, this list of competencies was converted into a questionnaire consisting of 5-point lickert scale. The participants were asked to rate each competency based on his/her perceptions, to indicate the extent to which a given competency is appropriate for incorporation into the Higher National Diploma (HND) electrical/electronic engineering curriculum in Nigeria. In essence, the objectives of the round 2 Delphi survey are: to obtain a quantifiable decisions of each Delphi participant about their perception of each competency; to gain an early insight into the appropriateness or otherwise of the competencies by

TABLE 3. Summary of retained and dropped competencies after Delphi round 3 analyses.

S/No	SUBTHEMES	RETAINED (%)	DROPPED (%)	TOTAL (%)
A	Cognitive-Related Competencies	18 (54.54%)	15 (45.45%)	33 100(%)
B	Psychomotor-Related Competencies	27 (71.05%)	11 (28.95%)	38 100(%)
C	Affective-Related Competencies	07 (43.75%)	09 (56.25%)	16 (100%)
	Total	**52** (59.77%)	**35** (40.23%)	**87** (100%)

subjecting them under a lickert scale of measurement; and to reveal an early indications of consensus by the panel of participants about which of the competencies might relate to the context of technical sustainability. At the end of the Delphi round 2 exercises, the researchers retrieved the questionnaires from all the participants. Entries of the ratings of each participant were made in to the IBM SPSS statistics version 20. The median and inter quartile range (IQR) of each competency were computed.

The results of the Round 2 Delphi survey were used to construct the round 3 questionnaire of the study. In the third and final round, each Delphi participant received a round 3 questionnaire that includes the competencies and their ratings (median and IQR) summarized by the researcher from round two. We asked the participants to revise his/her judgments or to specify the reasons for remaining outside the consensus. Of course participants' scores were not revealed to the entire group, but only to participant who owned the score. This round gives Delphi participants an opportunity to made further clarifications of both the information and their judgments of the relative importance of the competencies. The objectives of the Delphi round 3 include: to provide to the participants, feedback from the Delphi round 2; to provide an opportunity to challenge the results of the study judgments made during the round 2 analysis; to reach a final consensus or indicate that consensus cannot be reached for each competency. Subsequently, the researchers retrieved the round 3 questionnaire from all the Delphi participants. Entries of the ratings of each competency and for each participant were made into the IBM SPSS statistics version 20 software. The mean, median, SD, IQR, and percentage were computed. Reference [22] reported that albeit there is no agreement in the literature on the best method used to determine consensus, a systematic review including 80 Delphi studies found that the most frequently used method to achieve consensus was median scores and IQRs. This method was considered robust among many researchers including [12], [59], and [67].

From the round three feedbacks and consistent with the previous studies, competencies in which the median was equal or greater than 4, and/or which 75% of the Delphi participants' votes fall between 4-5 categories in a 5-point scale were considered appropriate for inclusion into the Higher National Diploma electrical/electronic engineering curriculum in Nigeria (Habibi, Sarafrazi and Izaydar, 2014). As a consequence, in the cognitive-related domain, 18 competencies were retained, while 15 competencies were dropped. Similarly, in the psychomotor-related domain, 27 competencies were retained, while 11 competencies were dropped. Likewise, in the affective-related domain, 7 competencies were retained, while 9 competencies were dropped. The table 3 below shows the summary of the retained and dropped competencies across the subthemes.

2) INFERENTIAL STATISTICS

The researchers employed the use of Wilcoxon non-parametric rank test to check the consensus between Delphi survey rounds 2 and 3, as well as Mann-Whitney U-Test to test the significance difference between the two groups of respondents.

a: CHECKING THE CONSENSUS BETWEEN DELPHI ROUNDS 2 AND 3

H_0: *the median of different between Round 2 and Round 3 equals to Zero*

To test this hypothesis, the Wilcoxon non-parametric rank test was used to test the consensus between the subthemes in Delphi rounds 2 and 3. The consensus is occurring when the stability of the dispersion around the median is determined. Table 4 below presents the hypothesis summary. The table 4 presented the various significant values of agreement for the subthemes in the study. The significant level is 0.05; and if the significant value exceeds 0.05, then the null hypothesis is retained, otherwise it has to be rejected. In these cases, the null hypotheses were retained for the cognitive-related, psychomotor-related and affective-related competencies. Thus, the study can safely conclude that based upon dispersion about the median, the consensus was achieved between Delphi Round 2 and Delphi Round 3, and therefore the rounds of the Delphi survey has come to an end.

b: TESTING THE STUDY HYPOTHESES

H_0: *The perceptions of the respondents do not differ significantly on the competencies in the technical sustainability suitable for incorporation into HND electrical/electronic engineering curriculum in Nigeria.*

The results of analysis as presented in table 5 shows that there is no significant difference ($p>0.05$) between the perceptions of lecturers in the polytechnics and that of personnel in industries on the competencies in technical sustainability suitable for incorporation into HND electrical/electronic engineering curriculum in Nigeria. As shown in the table, the p-values for cognitive-related,

TABLE 4. Hypotheses testing to establish the consensus between Delphi rounds 2 and 3.

Subthemes	Null Hypothesis	Test	Sig. Value	Sig. Level	Decision
Cognitive-related competencies	The median of different between Delphi Round 2 and Delphi Round 3 equals to Zero	Related Sample Wilcoxon Signed Rank Test	**.954**	**.05**	Retain the null hypothesis
Psychomotor-related competencies	The median of different between Delphi Round 2 and Delphi Round 3 equals to Zero	Related Sample Wilcoxon Signed Rank Test	**.077**	**.05**	Retain the null hypothesis
Affective-related competencies	The median of different between Delphi Round 2 and Delphi Round 3 equals to Zero	Related Sample Wilcoxon Signed Rank Test	**.709**	**.05**	Retain the null hypothesis

TABLE 5. Mann-Whitney U-Test of difference between the perceptions of lecturers and industrial personnel on the competencies in technical sustainability.

Subthemes	Null Hypothesis	Test	Sig. Value	Sig Level	Decision
Cognitive-related competencies	The distribution of scores is the same across the 2 categories of group	Independent Samples Mann-Whitney U-Test	.146	.05	Retain the null hypothesis
Psychomotor-related competencies	The distribution of scores is the same across the 2 categories of group	Independent Samples Mann-Whitney U-Test	.654	.05	Retain the null hypothesis
Affective-related competencies	The distribution of scores is the same across the 2 categories of group	Independent Samples Mann-Whitney U-Test	.796	.05	Retain the null hypothesis

psychomotor-related, and affective-related competencies are 0.146, 0.654, and 0.796 respectively. This warrants the researcher to retain the null hypothesis in all the cases, and declared that the perceptions of the 2 groups of participants in the Delphi survey do not statistically differ with respect to competencies in technical sustainability.

D. EXPLORATORY FACTOR ANALYSIS

An exploratory factor analysis (EFA) was performed to cluster the 18 competencies in cognitive-related realm, 27 competencies in psychomotor-related realm and 7 competencies in affective-related realm. It is important to reduce the number of variables to a smaller set that detects structure in the relationships between variables. This segment presents the statistical findings of the exploratory factor analysis, where principal component analysis and varimax rotated with Kaiser Normalization was used. This is carried out with the help of SPSS 20. Based on the factor selection procedures, we apply the logic of Kaiser-Guttman rule in the study [1]. In this rule, the number of factor is determined by how many eigenvalues are greater than 1.0.

1) EFA FOR COGNITIVE-RELATED COMPETENCIES

The results of EFA on cognitive-related competencies produced three factors as illustrated in Table 6 below. The fourth factor shown in the table has an eigenvalue less than 1, and is then not included as an independent factor. It is important to stress here that the fundamental object of EFA is to determine the number of latent variables or factors and detect the characteristics of those factors by means of variance and covariance among a set of observed measures [16].

Having established the number of factors, the results of the SPSS statistical analysis (varimax rotated) is applied to identify the factors of each of the competency. Table 7 below shows the factor loadings revealed by the SPSS principal component analysis. There were no general rules for selecting good factor loadings. As a consequence, we used 0.6 as a cut-off point for selecting the good factor loadings. One item (i.e. item 21) had a cross loadings and this was argued amongst the experts in engineering sustainability, who concluded that it could be suitably grouped as part of the 'Research and Development category'. Naming the factors is usually based on the content of the items by interpreting items in the factor (Kenny, et al, 2006).

TABLE 6. Principal component analysis from SPSS for cognitive-related competencies.

Factor	Eigenvalues	Percentage Variance	Cumulative Percentage
1	11.370	63.169	63.169
2	1.697	9.425	72.594
3	1.035	5.752	78.346
*4	0.710	3.947	82.293

TABLE 7. Factor loadings (rotated matrix) of cognitive-related competencies.

Items	Cognitive-Related Competencies	Factor 1	Factor 2	Factor 3
Item33	Understand the concept of maintainability and reliability in relation to sustainable energy sources	**.835**	.292	.256
Item30	Knowledge of the main topics and models that can be applied to the use of technology to achieve integrated ecological and technological objective with respect to sustainable energy sources	**.833**	.344	.199
Item25	An ability to analyze social and environmental benefits when sustainable energy sources are utilized for engineering activities	**.823**	.182	.289
Item22	Understanding of how material waste can be recovered, recycled or reused	**.810**	.236	.181
Item26	Understand and evaluate the impact of professional engineering work in the solution of complex problems in societal and environmental contexts	**.788**	.107	.156
Item32	Identifying the roles of engineering societies and their responsibilities with regards to reducing carbon footprint	**.761**	.203	.510
Item24	Recognize the need to use renewable resources	**.736**	.349	.276
Item23	An understanding of how waste energy can be utilized to provide heating directly or indirectly through incineration	**.721**	.422	.230
Item2	Ability to minimize the emission of GHGs by machines, equipment systems, or processes to meet desired needs within realistic constraints such as environmental, economic or social sustainability	**.649**	.095	.549
Item29	Understanding of the interrelation between product, process and environment, and the dynamics of technological change	**.626**	.490	.335
Item7	Understand that established design principles are used to evaluate existing designs, to collect data and to guide the design process	.277	**.844**	.146
Item6	Understand that design requirements, such as criteria, constraints and efficiency, sometimes compete with each other	.062	**.823**	.437
Item5	Examine how the design needs to continually be evaluated and the ideas of the design must be redefined and improved	.308	**.821**	.247
Item9	Analyzing the process of engineering design accounts for a number of factors to make decisions	.360	**.564**	.551
Item17	Evaluate the design solutions using conceptual, physical and mathematical models at various intervals of the design process in order to check for proper design and to note areas where improvements are needed	.550	**.563**	.378
Item10	Understand that technological problems must be researched before they are solved	.197	.268	**.826**
Item1	Ability to explore novel knowledge and understanding of design for the solutions to unfamiliar problems	.372	.322	**.690**
Item21	Research and explain new and emerging careers in (green) energy management and power systems	.211	.620	**.659**

The three category names developed for the factors in cognitive-related realm by the research team are: Factor 1: Clean Energy, Factor 2: Eco-Design and Factor 3: Research and Development (R&D). The category of clean energy encompasses 10 items (items 33, 30, 25, 22, 26, 32, 24, 23, 2, and 29), and have the highest composite mean score of 4.06.

TABLE 8. Principal component analysis from SPSS for psychomotor-related competencies.

Factor	Eigenvalues	Percentage Variance	Cumulative Percentage
1	15.899	58.885	58.885
2	2.964	10.978	69.863
3	1.719	6.337	76.198
4	1.109	4.107	80.305
*5	0.929	3.440	83.745

Eco-Design group consists of 5 items (items 7, 6, 5, 9 and 17) with the lowest composite mean score of 3.96. In comparison with the other categories, the Delphi participants consider these competencies to be less important than others in the set. Similarly, the category of R&D comprises of 3 items. This includes items 21, 10 and 1, having composite mean score of 4.03.

2) EFA FOR PSYCHOMOTOR-RELATED COMPETENCIES

The results of EFA on psychomotor-related competencies produced four factors as shown in Table 8 below. The fifth factor shown in the table has an eigenvalue less than 1, and is then not included as a separate factor.

Four factors were entrenched under psychomotor-related competencies, and the result of the SPSS statistical analysis (varimax rotated) is applied to identify the factors of each of the competency. Table 9 below shows the factor loadings revealed by the SPSS principal component analysis. As stated earlier, no general rule was available in selecting the good factor loadings, which necessitated the authors to use 0.6 as a cut-off point. One item (i.e. item 22) had a cross loadings and this was deliberated amongst the experts in engineering sustainability, who concluded that it could be suitably grouped as part of 'Sustainable Production' category. The four category names developed by the research team are: Factor 1: sustainable production, Factor 2: waste-to-energy-technology, Factor 3: communications and Factor 4: use of modern engineering software tools.

The category of sustainable production encompasses 9 items (items 21, 23, 4, 1, 9, 6, 22, 32, and 2), and have the lowest composite mean score of 4.08. Waste-to-energy-technology group consists of 9 items (items 28, 26, 5, 30, 31, 38, 14, 12, and 34) with the second lowest composite mean score of 4.09. Clustered competencies under communications consist of 7 items (items 13, 15, 8, 11, 35, 36, and 10), and have the second highest composite mean score of 4.14. Similarly, the category of 'Use of modern engineering software tools' are made up of 2 items (items 3, and 37) and has the highest composite mean score of 4.25. In comparison with the other categories, the Delphi participants consider these competencies to be more important than the others in the set.

3) EFA FOR AFFECTIVE-RELATED COMPETENCIES

The outcome of EFA on affective-related competencies produced only one factor as shown in Table 10 below. The second factor shown in the table has an eigenvalue less than 1, and is therefore not included as a separate factor.

Only one factor was established in affective-related competencies, which indicates that all the competencies here correlate well with each other. In other words, since only one factor was extracted, the solution cannot be rotated. Table 11 below shows the retained/approved competencies by the Delphi participants.

Having established and validated the competencies in technical sustainability theoretically and empirically, the figure 2 below illustrates the conceptual model of technical sustainability for integration into HND electrical/electronic engineering curriculum in Nigerian polytechnics. The model was developed by the researchers based on the research findings as shown.

V. DISCUSSION AND IMPLICATIONS

The objective of this study was to investigate the competencies (knowledge, skills and attitudes) in technical sustainability suitable for integration into HND electrical/electronic engineering curriculum in Nigeria. It was achieved using mixed-method study, in which sequential exploratory design is adopted. Initially, the authors conducted a qualitative study through document analysis and semi-structured interviews. Subsequently, a quantitative study was conducted using three rounds of modified Delphi survey with experts in academia and industry. The findings revealed competencies suitable for incorporation, and therefore an integrated discussion of qualitative and quantitative findings is presented. It is worthy to stress here that the findings of the qualitative phase is used in formulating the round 1 questionnaire, and therefore the discussion merge and interpret both qualitative and quantitative findings in relation to the competencies in technical sustainability.

A. DISCUSSION OF FINDINGS OF COGNITIVE-RELATED COMPETENCIES IN TECHNICAL SUSTAINABILITY

The findings of the study on cognitive-related competencies of technical sustainability revealed that 18 competencies are adjudged suitable for incorporation into HND electrical/electronic engineering curriculum in Nigeria, while 15 competencies were regarded inappropriate. In order to cluster the competencies into more meaningful key categories, an exploratory factor analysis was carried out, and the results reveal that the 18 competencies fell into 3 groups as follows: (1) Clean Energy, (2) Eco-Design, and (3) Research and Development (R&D). Based on these findings, therefore, it is evident that inculcating these competencies into HND electrical/electronic engineering curriculum will fully

TABLE 9. Factor loadings (rotated matrix) of psychomotor-related competencies.

Items	Competencies	Factor 1	Factor 2	Factor 3	Factor 4
Item21	Demonstrate efficient use of energy resources related to power and energy technology	**.907**	.139	.212	.039
Item23	Demonstrate the application of the Design Process to solve a problem related to technology, power and energy systems	**.840**	.168	.282	.076
Item4	Keep harvest rates of renewable resource inputs within regenerative capacities of the natural system that generates them	**.833**	.256	.163	.182
Item1	Ability to use creativity to develop new and original ideas and methods of sustainable production	**.794**	.017	.148	.239
Item9	Construct a prototype as a working model used to test a design concept by making actual observations and necessary ecological adjustments	**.731**	.098	.169	.307
Item6	Design and sustainably produce for re-usability and recyclability	**.688**	.237	.531	.273
Item22	Ability to demonstrate how new and emerging technology will be developed for efficient use of energy resources	**.664**	.605	.283	-.141
Item32	Upgrade skills to cope with current trend of sustainable production in line with socio-economic and socio-technical changes and environmental sustainability	**.641**	.216	.350	.493
Item2	Select environmentally friendly materials, and processes in engineering productions	**.629**	.192	.272	.558
Item28	Understand factors that contribute to degradation of resources and the need for restoration	.231	**.873**	.160	.148
Item26	Use waste as input resources to engineering processes	-.032	**.798**	.214	.226
Item5	Keep depletion rates of non-renewable resource inputs below the rate at which renewable substitutes are developed	.031	**.712**	.354	.441
Item30	Handle hazardous materials safely in recycling/reuse activities	.169	**.688**	.456	.279
Item 31	Observe accident prevention techniques in recycling/reuse activities	.476	**.657**	-.015	.143
Item38	Ability to safely and skillfully carry out the burning of waste using municipal solid waste incineration	.611	**.650**	.070	-.068
Item14	Knowledge and skills of co-processing as an effective waste-to-energy option in municipal solid waste management	.352	**.625**	.501	.217
Item12	Knowledge and skills of waste quantities and characteristics	.502	**.625**	.302	.152
Item34	Adequate skills in carrying out regular maintenance in waste-to-energy plants	.156	**.596**	.346	.506
Item13	Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques	.266	.160	**.903**	.031
Item15	Use computers and calculators to access, retrieve, organize, process, maintain, interpret and evaluate data and information in order to communicate	.424	.384	**.706**	.151
Item8	Interpret design problems in a clearly defined form	.263	.391	**.625**	.470
Item11	Communicate observation, processes and results of the entire design process, using verbal, graphic, quantitative, virtual and written means in addition to design models	.003	.590	**.621**	.250
Item35	Communicate adequately with other stakeholders in the surrounding of the technical system	.462	.303	**.615**	.218
Item36	Skills in the use of information and communication technologies	.385	.135	**.614**	.468
Item10	Ability to search for, process and analyze information from a variety of sources	.345	.288	**.558**	.538
Item3	Apply techniques, skills, and modern engineering tools necessary for engineering practice	.356	.479	.087	**.678**
Item37	Ability to use recent engineering software tools to solve sustainability problems and develop projects under the sustainability paradigm	.179	.549	.340	**.603**

TABLE 10. Principal component analysis from SPSS for affective-related competencies.

Factor	Eigenvalues	Percentage Variance	Cumulative Percentage
1	5.051	72.163	72.163
*2	0.610	8.711	80.874

TABLE 11. Results of round 3 Delphi survey analyses for affective-related competencies.

S/N	Competency	Mean	Med.	SD	IQR	%	Remark
1	An understanding of engineering professional and ethical responsibility	4.39	4.50	0.68	1.00	89.30	**Retained**
2	Identify safety and health protections and procedures that are critical to worker wellbeing	4.21	4.00	0.73	1.00	82.20	**Retained**
3	Ability to learn how to cooperate with others in a way to exhibit respect for individual and cultural differences and for the attitudes and feeling of others	4.17	4.50	0.72	1.00	82.10	**Retained**
4	Recognize characteristics and benefits of teamwork, leadership, citizenship in the school, community and industrial settings	4.03	4.00	0.96	1.75	75.00	**Retained**
10	Embrace change brought about by technical sustainability with an open-mind and with confidence	4.14	4.00	0.75	1.00	78.60	**Retained**
15	Need to recognize and value diversity, intra and inter-generational equity and natural ecosystems	3.96	4.50	0.92	1.75	75.00	**Retained**
16	Conservation of energy laws and regulations	4.28	4.00	0.76	1.00	82.10	**Retained**

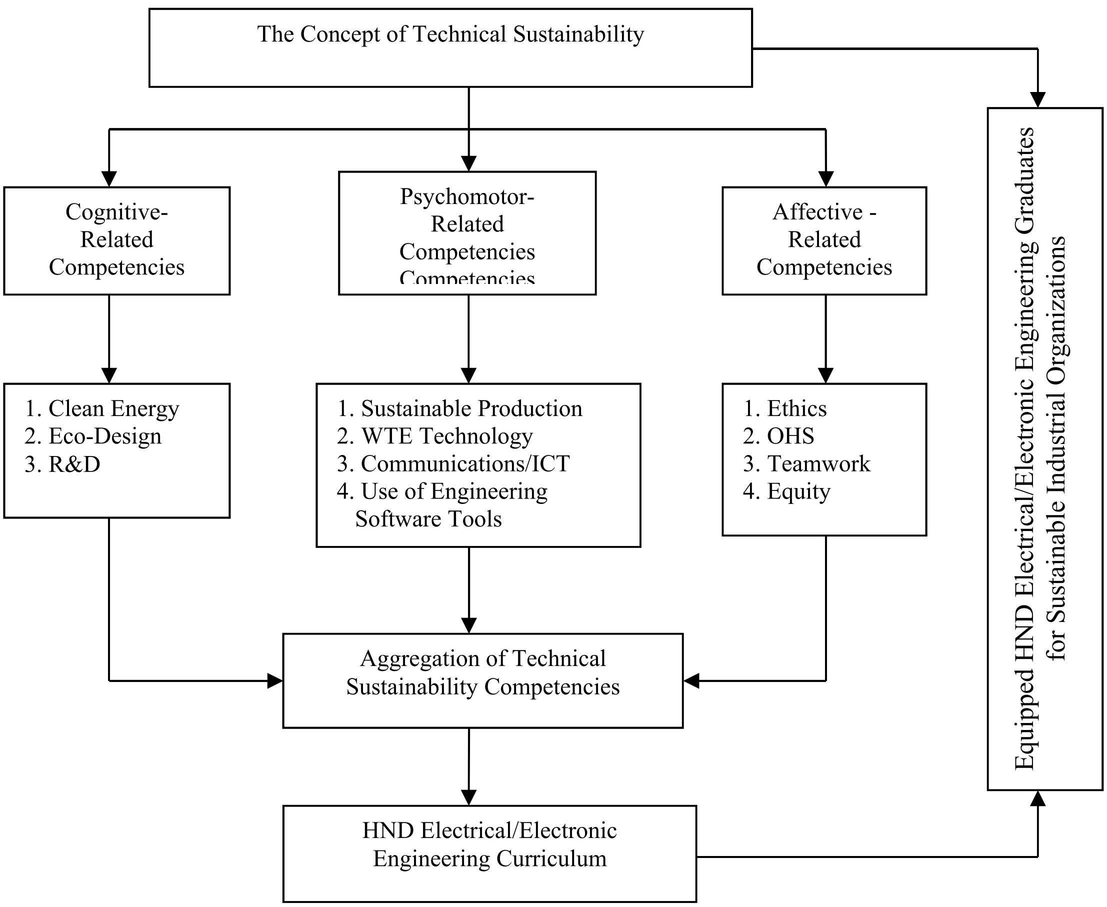

FIGURE 2. Conceptual model of technical sustainability for integration into HND electrical/electronic engineering curriculum in Nigeria.

prepare the graduates to work in the manufacturing industries, whose focus now is on sustainable design and production. Their contributions as technicians and/or technologists will help in uplifting of such industries, and will manifest in the societal growth and development. This indicates that there is need for the curriculum developers in Nigeria to incorporate cognitive-related competencies in technical sustainability in order to accelerate the achievement of sustainable development goals in the country. This finding is consistent with [2] who stressed the need to capture concepts of clean energy such as energy efficiency, renewable energy utilization and application into engineering disciplines in universities. Also [9] argued that while the world's electricity demand is rapidly growing, traditional energy resources are fast diminishing, which makes the clean energy sources humans' lone option. As a result, there is increased need for skilled engineers and technicians in these spheres, which translate to the development of innovative curricula, new courses and laboratories to train students for jobs in these rapidly developing industries. Several better and cleaner ways are in existent today in meeting people's energy needs. Clean energy resources such as wind and solar power generate electricity with little or no pollution and global warming emissions.

The findings are also in line with the study outcome of [57] that in order for society to adjust its consumption patterns, production and energy consumption, integrating the principles of eco-design into the skills and knowledge of imminent engineers is a necessary challenge. This finding is also corroborated by the work of [15] in which they designed an eco-design course to give a chance to develop the conceptual framework of environmental engineering, so as to facilitate the students' skills in innovation with regards to their industrial design processes via embedding ecological, social and economic factors. Eco-design entails designing or redesigning products, services, processes, or systems to evade or fix injury to the environment, society and the economy. It is everywhere as in sustainable flooring, green energy heating systems, eco-friendly packaging and recyclable products.

Furthermore, the study findings revealed a strong indication to capture cognitively-related competencies in R&D with respect to technical sustainability. This finding is supported by [34] that students benefit academically from involving in research through provision of actual world experience beyond conventional lecture class. It gives the students a chance to enhance their comprehension of research methods, practice communication skills as well as work together in specialized approach with others [43]. In realizing the immense benefits of R&D in engineering education, [11] instituted a novel didactic concept to combine the benefits of research-based learning approaches. Students' acquisition of requisite competencies in the practices of R&D can be a crucial decisive moment for their personal development and the development of professional skills desired by employers.

B. DISCUSSION OF FINDINGS OF PSYCHOMOTOR-RELATED COMPETENCIES IN TECHNICAL SUSTAINABILITY

The findings of the study in this section revealed that the Delphi participants agreed with the inclusion of 27 psychomotor-related competencies into HND electrical/electronic engineering curriculum, while rejecting 11 others. As stated earlier, these competencies were clustered through exploratory factor analysis which results in 4 key groups. These are (1) Sustainable production encompassing 9 items and has the lowest composite mean score of 4.08; (2) Waste-to-energy-technology (WTE) also consisting of 9 items with the second lowest composite mean score of 4.09; (3) Communication which consists of 7 items and has the second highest composite mean score of 4.14; and (4) Use of modern engineering software tools comprising of 2 items and have the highest composite mean score of 4.25. In comparison with the other categories, the Delphi participants consider these competencies to be more important than the others in the set.

The findings indicated the need for incorporation of competencies in sustainable production, which is confirmed by [11] who reported on the development of a course in engineering education that dealt with concepts, methods and tools for the design of a sustainable industrial production. They claimed that the course will prepare students as potential engineers, conscious of their task, which occurs from the enormous impact of industrial systems on the environment and society. Sustainable production is seen as the creation of goods and services with the aid of processes and systems that are non-polluting, conserving of energy and natural resources, economically viable, safe and healthful for workers, communities and consumers. When an industrial production is carried out in a sustainable approach, then the benefits extend to the environment, the employees, the communities, and the organizations. These conditions can lead, always in the long term, and often in the short term, to more economically viable and productive enterprises.

The findings also demonstrated that the participants approved the inclusion of competencies in WTE technologies, which is the process of generating energy in the form of electricity and/or heat from the incineration of waste. It is crucial for engineering departments in developing countries to enrich the curricula with competencies in WTE technologies because of the present energy catastrophe and the volumes of solid waste that are growing at an appalling level which continued to be a challenge for every country. In support of this view, [5] stated that several studies carried out to evaluate the viability of using municipal solid waste for energy production have revealed a positive result. This is also consistent with [53] who believed that WTE technologies could play a vital role in contributing to the renewable energy production and reducing the cost of land filling and its related environmental impacts.

The findings indicated that competencies in communication (including information and communication technology (ICT)) are suitable for incorporation into the said curriculum, and are rated second most important among the key competency categories. This finding is in line with [33] who found that communication skills exhibited the worst mean gap among several non-technical skills that are relevant to engineers. This implies that engineering graduates' communication skills are desperately needed to be improved by the engineering educators for adequate employment in industries, and this includes an ICT skill that makes them good communicators. The finding is also in consonance with [41] who maintains that green ICT is inevitable in the process of transitioning towards sustainable society. This is a clear indication that communications and/or ICT skills that consist of written, oral and graphic skills; ability to communicate results qualitatively, quantitatively, electronically, and textually need to be incorporated into the HND electrical/electronic engineering curriculum in Nigeria, since it is the one of the economic development pillars to achieve national competitive advantage.

The competencies in the use of modern engineering software tools were also suggested as suitable for inclusion into the HND electrical/electronic engineering curriculum. Modern engineering software tools facilitate the development and understanding of technological systems, and the products affects appropriateness of technology. This finding is in harmony with ABET that engineering students should, at the point of graduation, be able to apply techniques, skills, and modern engineering software tools essential for engineering practice. Similarly, [35] stressed the need for engineering education programmes to adapt themselves to advanced development by discovering the competencies regarding engineering software tools to meet the industrial requirements and adhere to the newest vogue. Companies are in dire need of employees with requisite competencies to embed software in almost all kinds of modern products and services, since it is the key enabler for innovation. For that, it is only judicious for the engineering educators in Nigeria to update the curricula in view of the numerous benefits of the skills in engineering software tools.

C. DISCUSSION OF FINDINGS OF AFFECTIVE-RELATED COMPETENCIES IN TECHNICAL SUSTAINABILITY

The findings of the study also revealed that the Delphi participants agreed with the inclusion of 7 affective-related competencies into HND electrical/electronic engineering curriculum, while rejecting 9 others. Exploratory factor analysis produced only one factor which indicates that all the competencies correlate well with each other. These include engineering ethical responsibility, occupational health and safety (OSH), cooperation/teamwork, and equity. Engineering ethics is an important and an inevitable sphere of system of moral principles that apply to the practices of engineering. It assesses and lay down the responsibilities of engineers to society, clients and the profession. Reference [4] cited [40] who claimed that affective work-related skills are more vital in industries than theoretical and practical competencies put together. Despite its importance, [38] noted the absence of a framework for preparing engineering students to analyze ethical issues. As a consequence, they developed and tested an approach for improving the ethical reasoning of engineering students. Similarly, OSH was also identified for inclusion into the curriculum. It is a multidisciplinary field concerned with the safety, health and welfare of people at work. Its enforcement in industries is yielding positive results. For instance, the BLS reported that there were 43 (0.82%) less fatal occupational injuries in 2017 compared to 2016. In relation to this, [62] lament the shortage of skilled OSH experts that will meet the present as well as the imminent need for such expertise. Consequently, they stressed the need for OSH to be entrenched into engineering education curricula through mounting pertinent courses that will guarantee engineering students have access to education they require to carry out vital job tasks and protects them from risks and harmful industrial impacts.

Furthermore, cooperation/teamwork is suggested for incorporation into the curriculum. Teamwork is a cooperative endeavor by the cohort members to accomplish a collective object, while cooperation is the act of practice of keenly working collectively with respect to a mutual intent. These values are important as they allow people and groups to work together a common goal or desired mutual benefits. Engineering students necessarily require these values as their future jobs undoubtedly warrants them to work within groups at many levels of their careers. This finding is supported by [4] who found the following affective work skill needs for inclusion into engineering education curricula. These include 'ability to get along with coworkers', 'punctual to work', 'request other people's opinion', and 'honesty and trustworthiness'. Likewise, equity has also caught the attention of the participants for integration into the curriculum. Equity in the context of technical sustainability protects the health of communities and educates and empowers people to participate in the process, encouraging them to take action to improve their health and the surrounding environment. It can be both intra- and inter-generational equity. Intra-generational equity concerns with equality among the same generations with respect to the use of resources, while inter-generational equity is a value concept which centers on the right of future generations to inherit and equitably access the same diversity in natural and cultural resources. This finding has a tremendous support from the Brundtland Report in which the concept of equity was firstly referred as "...without compromising the ability of future generations to meet their own needs..." [66] also concurs with this finding that organizations (especially HEIs) that are determined to be socially and ecologically responsible would be well served by handling sustainability as a form of intergenerational social equity or fairness.

In essence therefore, encompassing affective-related competencies appropriately into HND electrical/electronic engineering curriculum will facilitate the transformation of the students to sustainability-literate graduates and contribute to increased professionalism, increased awareness of engineering's societal context, and thus allows them to make educated, sustainability-informed decisions on the overall welfare of the public.

VI. CONCLUSION

In view of the calls for HEIs to integrate sustainable development into their curricula, the authors, using mixed-method study, investigated competencies (cognitive-related, psychomotor-related and affective-related competencies) in technical sustainability suitable for incorporation into Higher National Diploma electrical/electronic engineering curriculum in Nigeria. Investigating and incorporating suitable competencies in technical sustainability will go a long way in enhancing engineering graduates' understanding of technical aspects of life. This understanding will help them deal adequately with the future sustainability challenges in the workplace and in the broader society. The study found that cognitive-related competencies in Clean Energy, Eco-Design, and R&D are suitable for incorporation into the curriculum. The study also discovered that psychomotor-related competencies in sustainable production, waste-to-energy-technology, communication/ICT, and use of modern engineering software tools are suitable for incorporation in to the curriculum. Similarly, the study uncovered that affective values related to engineering ethical responsibility, occupational health and safety, cooperation/teamwork, and equity are suitable for incorporation into the curriculum. As a result, the National Board for Technical Education (NBTE), as the accreditation body and curriculum developers for Nigerian polytechnics should organize and coordinate the processes of incorporating these competencies into the Higher National Diploma electrical/electronic engineering curriculum. This will help the students to have an intelligent understanding of the complexity of sustainable development, as well as prepare them in promoting technical and other aspects of sustainability, using better resource efficiency, reduced pollution, and reflection of the broader social effects of novel technologies, processes and practices.

REFERENCES

[1] Y. H. Ahn, R. P. Annie, and H. Kwon, "Key competencies for U.S. Construction graduates: Industry perspective," *J. Prof. Issues Eng. Educ. Pract.*, vol. 138, no. 2, pp. 123–130, 2012.

[2] A. A. Alawin, T. A. Rahmeh, J. O. Jaber, S. Loubani, S. A. Dalu, W. Awad, and A. Dalabih, "Renewable energy education in engineering schools in Jordan: Existing courses and level of awareness of senior students," *Renew. Sustain. Energy Rev.*, vol. 65, pp. 308–318, Nov. 2016.

[3] B. Atsumbe, "Mechanisms for improving manpower production in vocational and technical education," *Akoka J. Educ.*, vol. 1, no. 2, pp. 165–178, 2002.

[4] B. N. Atsumbe and T. Saba, "A study on affective work skills needs of engineering and technology education students of universities in North Central States of Nigeria," *Bayero J. Pure Appl. Sci.*, vol. 1, no. 1, pp. 95–98, 2008.

[5] M. K. Awasthi, S. Sarsaiya, H. Chen, Q. Wang, M. Wang, S. K. Awasthi, and Z. Zhang, *Global Status of Waste-to-Energy Technology Current Developments in Biotechnology and Bioengineering*. Amsterdam, The Netherlands: Elsevier, 2019, pp. 31–52.

[6] G. S. Barbosa, P. R. Drach, and O. D. Corbella, "A conceptual review of the terms sustainable development and sustainability," *J. Social Sci.*, vol. 3, no. 2, p. 1, 2014.

[7] G. Bascoul, J. Schmitt, D. Rasolofoarison, L. Chamberlain, and N. Lee, "Using an experiential business game to stimulate sustainable thinking in marketing education," *J. Marketing Educ.*, vol. 35, no. 2, pp. 168–180, 2013.

[8] S. A. Batterman, A. G. Martins, C. H. Antunes, F. Freire, and M. G. da Silva, "Development and application of competencies for graduate programs in energy and sustainability," *J. Prof. Issues Eng. Educ. Pract.*, vol. 137, no. 4, pp. 198–207, 2011.

[9] R. G. Belu and I. I. N. Husanu, "Embedding renewable energy and sustainability into the engineering technology curricula," presented at the ASEEE Conf. Expo., 2012.

[10] F. Besong and C. Holland, "The dispositions, abilities and behaviours (Dab) framework for profiling learners' sustainability competencies in higher education," *J. Teacher Educ. Sustainability*, vol. 17, no. 1, pp. 5–22, 2015.

[11] S. Blume, N. Madanchi, S. Böhme, G. Posselt, S. Thiede, and H. Herrmann, "Die Lernfabrik—Research-based learning for sustainable production engineering," *Procedia CIRP*, vol. 32, pp. 126–131, Jan. 2015.

[12] R. Boulkedid, H. Abdoul, M. Loustau, O. Sibony, and C. Alberti, "Using and reporting the Delphi method for selecting healthcare quality indicators: A systematic review," *PLoS ONE*, vol. 6, no. 6, 2011, Art. no. e20476.

[13] F. Boutin and C. Chinien, "Generic sustainable development skills for the workforce in Canada," in *Work, Learning and Sustainable Development*, J. Fien, R. Maclean, and M.-G. Park, Eds. Springer, 2009, doi: 10.1007/978-1-4020-8194-1.

[14] M. Braungart, W. McDonough, and A. Bollinger, "Cradle-to-cradle design: Creating healthy emissions-a strategy for eco-effective product and system design," *J. Cleaner Prod.*, vol. 15, nos. 13–14, pp. 1337–1348, 2007.

[15] B. Bravo-Díaz and P. J. Gutiérrez-Yurrita, "Eco-design as a tool to implement the new approach of the educational model by competencies in engineering courses," presented at the Conf. 8th Int. Conf. Educ., Res. Innov., 2015.

[16] T. A. Brown, *Confirmatory Factor Analysis for Applied Research*. New York, NY, USA: Guilford Press, 2006.

[17] L. K. Caldwell, "The concept of sustainability: A critical approach," in *Ecological Sustainability and Integrity: Concepts and Approaches*. Bloomington, IN, USA: Indiana Univ. Bloomington, 1998, pp. 1–15.

[18] V. D. Calhoun, K. A. Kiehl, and G. D. Pearlson, "Modulation of temporally coherent brain networks estimated using ICA at rest and during cognitive tasks," *Hum. Brain Mapping*, vol. 29, no. 7, pp. 828–838, 2008.

[19] S.-M. Cheah, K. Yang, and D. Sale, "Pedagogical approach to integrate sustainable development into engineering curriculum," presented at the 8th Int. CDIO Conf., 2012.

[20] P.-H. Chua and S.-M. Cheah, "Education for sustainable development using design thinking and appropriate technology," presented at the 9th Int. CDIO Conf., 2013.

[21] R. Ciegis, J. Ramanauskiene, and B. Martinkus, "The concept of sustainable development and its use for sustainability scenarios," *Eng. Econ.*, vol. 62, no. 2, pp. 28–37, 2009.

[22] M. Courtenay, P. Franklin, M. Griffiths, T. Hall, J. Macangus, J. Myers, F. Peniston-Bird, and K. Radley, "Establishing priorities range conditions managed by UK community practitioner nurse prescribers: A modified Delphi consensus study," *J. Adv. Nursing*, vol. 74, no. 8, pp. 1863–1874, 2018.

[23] A. R. Dainty, M. I. Cheng, and D. R. Moore, "A competency-based performance model for construction project managers," *Construct. Manage. Econ.*, vol. 22, no. 8, pp. 877–886, 2004.

[24] C. L. Dancz, K. J. Ketchman, B. P. Rebekah, R. Mahmud, M. M. Bilec, K. Parrish, and E. A. Adams, "Integrating sustainability grand challenges and experiential learning into engineering curricula: Years 1 through 3," presented at the ASEE Annu. Conf. Expo., 2016.

[25] *Framework for Action, Towards Inclusive and Equitable Quality*, I Declaration, UNESCO Together With UNICEF, Incheon, South Korea, 2015.

[26] C. Desha, "An investigation into the strategic application and acceleration of curriculum renewal in engineering education for sustainable development," Ph.D. dissertation, Griffith School Eng. Sci., Environ. Technol. Group, Griffith University, Mount Gravatt, QLD, Australia, 2010.

[27] A. Dobson, "Environment sustainabilities: An analysis and a typology," *Environ. Politics*, vol. 5, no. 3, pp. 401–428, 1996.

[28] G. R. Davies, "Appraising weak and strong sustainability: Searching for a middle ground," *Consilience, J. Sustain. Develop.*, vol. 10, no. 1, pp. 111–124, 2013.

[29] J. A. D. Pisani, "Sustainable development—Historical roots of the concept," *Environ. Sci.*, vol. 3, no. 2, pp. 83–96, 2006.

[30] J. Elkington, *Cannibals With Forks: The Triple Bottom Line of 21st Century Business*. London, U.K.: Wiley, 1999.

[31] *Capstone Publishing Limited Oxford Centre for Innovation Mill Street Oxford OX2 0JX United Kingdom*, Capstone Publishing Limited, Oxford, U.K., 1997.

[32] J. Elliott, *An Introduction to Sustainable Development*. Evanston, IL, USA: Routledge, 2012.

[33] M. K. Fathiyah, R. Hamid, A. A. Mutalib, and M. S. Rasul, ''Skills gap analysis: Satisfaction and expectation of engineering educators in Malaysia,'' *Int. J. Recent Technol. Eng.*, vol. 8, no. 2, pp. 447–454, 2019.

[34] D. L. Frame, ''A qualitative review of early undergraduate research from the perspective of faculty members, academic advisors, and undergraduate researchers (students) at a two-year college,'' J. Res. Pract. College Teach., vol. 2, no. 1, pp. 1–23, 2017.

[35] F. Gurcan and N. E. Cagiltay, ''Big data software engineering: Analysis of knowledge domains and skill sets using LDA-based topic modeling,'' *IEEE Access*, vol. 7, pp. 82541–82552, 2019.

[36] A. Habibi, A. Sarafrazi, and S. Izadyar, ''Delphi technique theoretical framework in qualitative research,'' *Int. J. Eng. Sci.*, vol. 3, no. 4, pp. 8–13, 2014.

[37] A. Z. Hamedani, ''Methodology and statistical analysis of sustainable transportation criteria for certification systems,'' Ph.D. dissertation, des Fachbereiches Bauingenieurwesen der Bergischen Univ. Wuppertal, Wuppertal, Germany, 2014.

[38] J. L. Hess, J. Beever, C. B. Zoltowski, L. Kisselburgh, and A. O. Brightman, ''Enhancing engineering students' ethical reasoning: Situating reflexive principlism within the SIRA framework,'' J. Eng. Educ., vol. 108, no. 1, pp. 82–102, 2019.

[39] J. Hugé, C. Mac-Lean, and L. Vargas, ''Maturation of sustainability in engineering faculties-From emerging issue to strategy?'' *J. Cleaner Prod.*, vol. 172, pp. 4277–4285, Jan. 2018.

[40] D. N. Huntzinger, M. J. Hutchins, J. S. Gierke, and J. W. Sutherland, ''Enabling sustainable thinking in undergraduate engineering education,'' *Int. J. Eng. Educ.*, vol. 23, no. 2, p. 218, 2007.

[41] A. Klimova, E. Rondeau, K. Andersson, J. Porras, A. Rybin, and A. Zaslavsky, ''An international master's program in green ICT as a contribution to sustainable development,'' *J. Cleaner Prod.*, vol. 135, pp. 223–239. Nov. 2016.

[42] K. Lindow, R. Woll, and R. Stark, ''A conceptual framework for sustainable engineering design,'' in *Leveraging Technology for a Sustainable World*. Berlin, Germany: Technische Universität Berlin, 2012, pp. 197–202.

[43] D. Lopatto, ''Undergraduate research as a high-impact student experience,'' *Peer Rev.*, vol. 12, no. 2, p. 27, 2010.

[44] R. Lozano, R. Lukman, F. J. Lozano, D. Huisingh, and W. Lambrechts, ''Declarations for sustainability in higher education: Becoming better leaders, through addressing the University system,'' *J. Cleaner Prod.*, vol. 48, pp. 10–19, Jun. 2013.

[45] S. Majumdar, ''Major challenges in integrating sustainable development in TVET,'' in *Proc. CPSC*, Manila, Philippines, 2009, pp. 1–15.

[46] N. Mukhtar, ''Occupational skills required by electrical engineering graduates of universities for effective performance in industries of Kano and Kaduna States, Nigeria, Unpublished M,'' TECH Thesis, Dept. Ind. Technol. Educ., Federal Univ. Technol., Minna, Nigeria, 2014.

[47] R. L. Nagel, E. C. Pappas, and O. Pierrakos, ''On a vision to educating students in sustainability and design—The James Madison university school of engineering approach,'' *Sustainability*, vol. 4, no. 1, pp. 72–91, 2011.

[48] R. M. Nickel, ''Strategies for incorporating sustainability into the curriculum,'' Wisconsin Tech. College Syst. Found., Waunakee, WI, USA, Tech. Rep., 2013.

[49] C. Noè, R. Pozzi, and A. Magni, ''Teaching sustainability to industrial engineering students,'' presented at the 43rd SEFI Annu. Conf. Diversity Eng. Educ., Opportunity Face New Trends Eng. (SEFI), 2015.

[50] D. Ojerinde. (2015). *Polytechnic Education in Nigeria: Prospects and Relevance*. Accessed: Apr. 5, 2017. [Online]. Available: https://www.google.com/

[51] M. A. Olinzock, A. E. Landis, C. L. Saunders, W. O. Collinge, A. K. Jones, L. A. Schaefer, and M. M. Bilec, ''Life cycle assessment use in the North American building community: Summary of findings from a 2011/2012 survey,'' *Int. J. Life Cycle Assessment*, vol. 20, no. 3, pp. 318–331, 2015.

[52] S. O'Rafferty, H. Curtis, and F. O'Connor, ''Mainstreaming sustainability in design education—A capacity building framework,'' *Int. J. Sustainability Higher Educ.*, vol. 15, no. 2, pp. 169–187, 2014.

[53] O. K. Ouda, S. Raza, A. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, ''Waste to energy potential: A case study of Saudi Arabia,'' *Renew. Sustain. Energy Rev.*, vol. 61, pp. 328–340, Aug. 2016.

[54] E. Pappas, ''A new systems approach to sustainability: University responsibility for teaching sustainability in contexts,'' *J. Sustainability Educ.*, vol. 3, no. 1, pp. 3–18, 2012.

[55] E. Pappas, O. Pierrakos, and R. Nagel, ''Using Bloom's taxonomy to teach sustainability in multiple contexts,'' *J. Cleaner Prod.*, vol. 48, pp. 54–64, Jun. 2013.

[56] B. Penzenstadler and H. Femmer, ''A generic model for sustainability with process- and product-specific instances,'' presented at the Workshop Green Softw. Eng., 2013.

[57] C. Perpignan, V. Robin, Y. Baouch, and B. Eynard, ''Ecodesign from high school to bachelor level: A French case study,'' presented at the Design Soc., Int. Conf. Eng. Design, 2019.

[58] J. Ribot, A. Najam, and G. Watson, ''Climate variation, vulnerability and sustainable development in the semi-arid tropics,'' in *The Earthscan Reader on Adaptation to Climate Change*. Jan. 2009, pp. 117–160.

[59] E. Rogozinska, M. D'amico, K. S. Khan, J. G. Cecatti, H. Teede, S. Yeo, and M. Perales, ''Development of composite outcomes for individual patient data (IPD) meta-analysis on the effects of diet and lifestyle in pregnancy: A Delphi survey,'' *BJOG, Int. J. Obstetrics Gynaecol.*, vol. 123, no. 2, pp. 190–198, 2016.

[60] M. A. Rosen, ''Engineering sustainability: A technical approach to sustainability,'' *Sustainability*, vol. 4, no. 9, pp. 2270–2292, 2012.

[61] E. Santoyo-Castelazo and A. Azapagic, ''Sustainability assessment of energy systems: Integrating environmental, economic and social aspects,'' *J. Cleaner Prod.*, vol. 80, pp. 119–138, Oct. 2014.

[62] J. G. Scott, E. Shore, C. Brown, C. Harris, and M. A. Rosen, ''Highlights from occupational safety and health continuing education needs assessment,'' *Amer. J. Ind. Med.*, vol. 62, no. 10, pp. 901–907, 2019, doi: 10.1002/ajim.23014.

[63] C. P. M. Sianipar, D. Kiyoshi, Y. Gatot, and A. Adhiutama, ''Seven pillars of survivability: Appropriate technology with a human face,'' *Eur. J. Sustain. Develop.*, vol. 2, no. 4, pp. 1–18, 2013.

[64] R. Siew, ''Human resource management in the construction industry—Sustainability competencies,'' *Construct. Econ. Building*, vol. 14, no. 2, pp. 87–103, 2014.

[65] S. L. Sproule and M. B. van Ryneveld, ''Knowledge uptake by technical professionals and decision-makers for developmental water services. Part 2: Individual competencies,'' *Water SA*, vol. 35, no. 4, pp. 399–413, 2009.

[66] E. C. Stazyk, A. Moldavanova, and H. G. Frederickson, ''Sustainability, intergenerational social equity, and the socially responsible organization,'' *Admin. Soc.*, vol. 48, no. 6, pp. 655–682, 2016.

[67] J. C. Thorn, S. T. Brookes, C. Ridyard, R. Riley, D. A. Hughes, S. Wordsworth, and W. Hollingworth, ''Core items for a standardized resource use measure: Expert Delphi consensus survey,'' *Value Health*, vol. 21, no. 6, pp. 640–649, 2018.

[68] *Rio Declaration on Environment and Development, The United Nations Conference on Environment and Development*, UNESCO, Rio de Janeiro, Brazil, 1992.

[69] *Education for Sustainability, From Rio to Johannesburg: Lessons Learnt From a Decade of Commitment. World Summit on Sustainable Development*, UNESCO, Johannesburg, South Africa, 2002. [Online]. Available: http://unesdoc.unesco.org/images/0012/001271/127100e.pdf

[70] *Report by the Director-General on the United Nations Decade for Education for Sustainable Development, International implementation Scheme and UNESCO's Contribution to the Implementation of the Decade, 172 EX/11*, UNESCO, Paris, France, 2005. [Online]. Available: http://unesdoc.unesco.org/images/0014/001403/140372e.pdf

[71] *Our Common Future*, World Commission Environ. Develop. (WCED), Oxford Univ. Press, Oxford, U.K., 1987.