Renewable and Sustainable Energy Reviews 187 (2023) 113776

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Critical skills needs and challenges for STEM/STEAM graduates increased employability and entrepreneurship in the solar energy sector

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ARTICLE INFO

Keywords:
Science, technology, engineering, and mathematics
Science, technology, engineering, art, and mathematics
Solar photovoltaic
Solar energy sector
Skills gap
Undergraduates
In-demand skills
Sustainable development goal 7

ABSTRACT

Energy produced by photovoltaic module (PVM) is poised to deliver the UN Sustainable Development Goal 7 (SDG-7) by 2030 and Net-Zero by 2050 but not until ample graduates with adequate Solar Energy Technology (SET) skills are produced by Higher education institutions (HEIs). Although PVM has witnessed significant penetration globally, the sustainability of the growth of the sector is challenged by attendant monotonic skilled labour shortages. The evolving growth imbalance is critical in the European Union (EU), limits her global competitiveness and necessitates the need to create wider awareness on the green technology to stimulate more production of solar energy sector (SES) specific skills graduates. Discussing the mismatch between the skills Europe needs and has in the SES, the study outlines key critical skills Science, Technology, Engineering and Mathematics (STEM) cum Arts (STEAM) graduates ought to possess to secure sector employment and the challenges limiting them from acquiring the competencies. The review is conducted via extensive study of relevant literature, analysis of interviews and observations. Academic, industrial, and entrepreneurial skills are identified as critical SES needs. Designing and running educational modules/curricula that embed the identified solar technology specialist skills on students and learners are proposed as vehicle to increase their employability and entrepreneurship. This study profiles trends and developments in the SES for stakeholders' increased awareness while presenting the specialist skills in-demand for employment in the sector. The adoption of SET Training (SETechTra) curricula/modules by the EIs will substantially increase the production of industry-ready graduates whilst decreasing the SES skills gap.

1. Introduction

Energy – in various forms – is needed to grow and sustain life on earth. On record, mankind has been harnessing energy to serve their needs which include manufacture of goods, transportation, production of foods, and powering of structures and systems for centuries. Since industrial revolution, energy has been generated in large quantities predominantly from fossil fuel and their derivatives. Whilst such generation has been serving mankind, it has recently been shown to be detrimental to the continued existence of life on earth through two main mechanisms. The activity is scientifically demonstrated to generate and liberate carbon dioxide (CO_2) and associated greenhouse gases to the ambient. The emission is believed to cause harmful climate change at effectively undisputable confidence level. The activity accelerates depletion of finite fossil-fuel reserves at an unsustainable rate predicted to run out in decades [1]. Furthermore, fossil fuel reliance is observed to introduce socio-economic and welfare inequalities as well as regional

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https://doi.org/10.1016/j.rser.2023.113776
Received 4 June 2023; Received in revised form 16 August 2023; Accepted 22 September 2023
Available online 29 September 2023
1364-0321/

Abbreviations and nomenclature

I. Science, Technology, Engineering, and Mathematics STEM
II. Science, Technology, Engineering, Art, and Mathematics STEAM
III. Photovoltaic Module PVM
IV. UN Sustainable Development Goal 7 SDG-7
V. Solar Energy Technology SET
VI. Solar Energy Technology Sector SETS
VII. Higher Education Institutions HEIs
VIII. European Union EU
IX. Solar Energy Sector SES
X. Solar Energy Technology Training SETechTra
XI. Carbon dioxide CO_2
XII. International Monetary Fund IMF
XIII. Photovoltaic PV
XIV. Solar Energy SE
XV. Direct Current DC
XVI. Alternating Current AC
XVII. International Electrotechnical Commission IEC
XVIII. Concentrated Solar Power CSP
XIX. Education and Training E&T
XX. Crystalline Silicon Photovoltaics c-Si PV
XXI. Dye-sensitized Solar Cells DSSCs
XXII. Virtual Power Plant VPP

Units
i. Watts per square metre W/m^2
ii. Giga watts GW
iii. Mega watts MW
iv. Terawatt hour TWh

labour market distortions with potential cross-border conflicts which are likely to worsen in the presence of resource depletion [1]. The negative global impacts of climate change on terrestrial life and environment are reported by many researchers including [2,3]. In 2021, four key climate change indicators – greenhouse gas concentrations, sea level rise, ocean heat, and ocean acidification – set new record highs.

As the main cause of climate change is generation of energy from fossil fuels, the key to tackling the crisis is to end our reliance on fossil fuels. This finding necessitates a holistic transformation of our energy systems. A shift from fossil fuel energies to renewable energies is the means to achieving terrestrial sustainability which will guarantee future on earth amidst global climate change. A critical action which will fast-track the transformation is to shift energy subsidies from fossil fuels to renewable energy. Another vital action would be to reduce fossil fuel combustion through the design and use of technologies that increase energy efficiency whilst reducing energy load as demonstrated by digital energy management systems [4]. Complete removal or significant reduction of harmful CO_2 emissions within a clean energy framework implemented by carbon capture and storage (CCS) technologies is yet another positive action [5]. Fossil-fuel subsidies are a major financial barrier hindering the world's shift to renewable energy. The International Monetary Fund (IMF) reported in Ref. [6] that globally, fossil fuel subsidies were $5.9 trillion in 2020 or about 6.8% of GDP and are expected to rise to 7.4% of GDP in 2025. This statistic represents about $11 billion a day. It is found from review that roughly 50% of the public resources spent to aid consumption of fossil fuel benefits the richest 20% of the population. This revelation further makes the fossil fuel subsidies inefficient and inequitable. Shifting subsidies from fossil fuels to renewable energy will drive societal sustainable economic growth by creating new jobs. In addition, it will drastically reduce harmful emission whilst thriving improved and better public health. There will be equity and equality as the poor and most vulnerable society around the world will feel considered. The shift is accelerated by the adoption of the seventeen Sustainable Development Goals (SDGs) by the United Nations General Assembly (UNGA) in 2015. Goal number 7 on affordable and clean energy demands that access to affordable, reliable, sustainable, and modern energy for all be ensured by 2030. Fast-tracking the goals – especially the number 7 – has galvanised many research studies which include [7–12].

Renewable energy technologies offer promise for this shift. All the available and foreseen technologies, including wind, tidal, hydro and geothermal have a range of positive and negative characteristics – most being heavily location-dependent and environmentally sensitive [13]. However, solar photovoltaic (PV) technology stands out among the renewable energy technologies to be used to actualise the agenda for several reasons. As it is now pertinent that urgent support in the energy transition is vital, discussion on the state-of-the-art in solar PV technology is presented to provide a holistic background and awareness on the much-needed technology. Categorically, two states-of-the-art in the technology of solar PV are discussed. The first is the technology principles, advancements, and basic architecture – including the fundamental operations of both the module and the system. The second is the economics of the technology - focusing on the technology penetration. SETs are the technologies designed to harness the energy from the sun to provide electrical and thermal energies. The sun emits energy in the form of rays characterised by heat-infrared and light-visible cum ultraviolet rays. The earth receives about 71% of the sun's emitted rays in the magnitude of 1360 W/m^2 and account for circa 1000 W/m^2 after reflecting approximately 29% of the rays. The atmosphere - consisting of water vapour, dust, and ozone - absorb 23% with land and sea receiving 48% of the energy. Exploitation of the energy using suitable technologies becomes attractive on discovery that the sun in 1 h generates an amount of electrical energy sufficient to power the entire planet for one year. This assertion is supported by Ref. [14]. A realisation that solar energy (SE) is clean, mostly abundant, evenly distributed and very competitive positions its technologies as the best green energy technologies to deliver the UN sustainable development goal 7 b y 2030 as well as the Net Zero target and global climate-neutrality goals by 2050. The key technologies include photovoltaics (PV), solar thermal (PV-T), concentrated solar power (CSP), and solar heating.

A smallest unit of energy production, known as the cell, exist in each technology. In PV technology, developed cell technologies are the crystalline silicon PV and thin-film PV cells. The family of crystalline silicon cells has mono-crystalline and poly-crystalline cells as members while the thin-film cells set has amorphous silicon (A-Si), Copper Indium Gallium Selenide (CIGS), Cadmium telluride (CdTe), Gallium arsenide (GaAs) cells as the sub-set. Evolving technologies include perovskite PV cell, dye PV cell, concentrated PV cell, silicon germanium (SiGe) PV cell, Nanofibre PV cell and multi-junction/Tandem/Cascaded PV cell. In each of the cells, a substance absorbs the light or heat in the sun's rays and convert it into energy. A schematic classification of PV cell technologies is shown in Fig. 1. The c-Si PV cell is the most widely adopted cell and Fig. 2 presents a basic architecture of a *P*-type crystalline silicon PV cell. The assembly materials are depicted and the flow of electron from the front electrical contact to the load and then out to the back electrical contact into the cell is represented.

The solar cells are interconnected to form a module which are interconnected to form a photovoltaic field also known as solar farm. The key components of a c-Si PV module are c-Si solar cell, silver contacts at the front, aluminium contact at the back, interconnecting copper ribbons and solder interconnects. Fig. 3, adapted from Ref. [15], presents the photovoltaic module in operation whilst detailing its basic principles. The incident heat and light rays from the sun strikes the glass surface of the c-Si PV module. The infrared component of the ray is

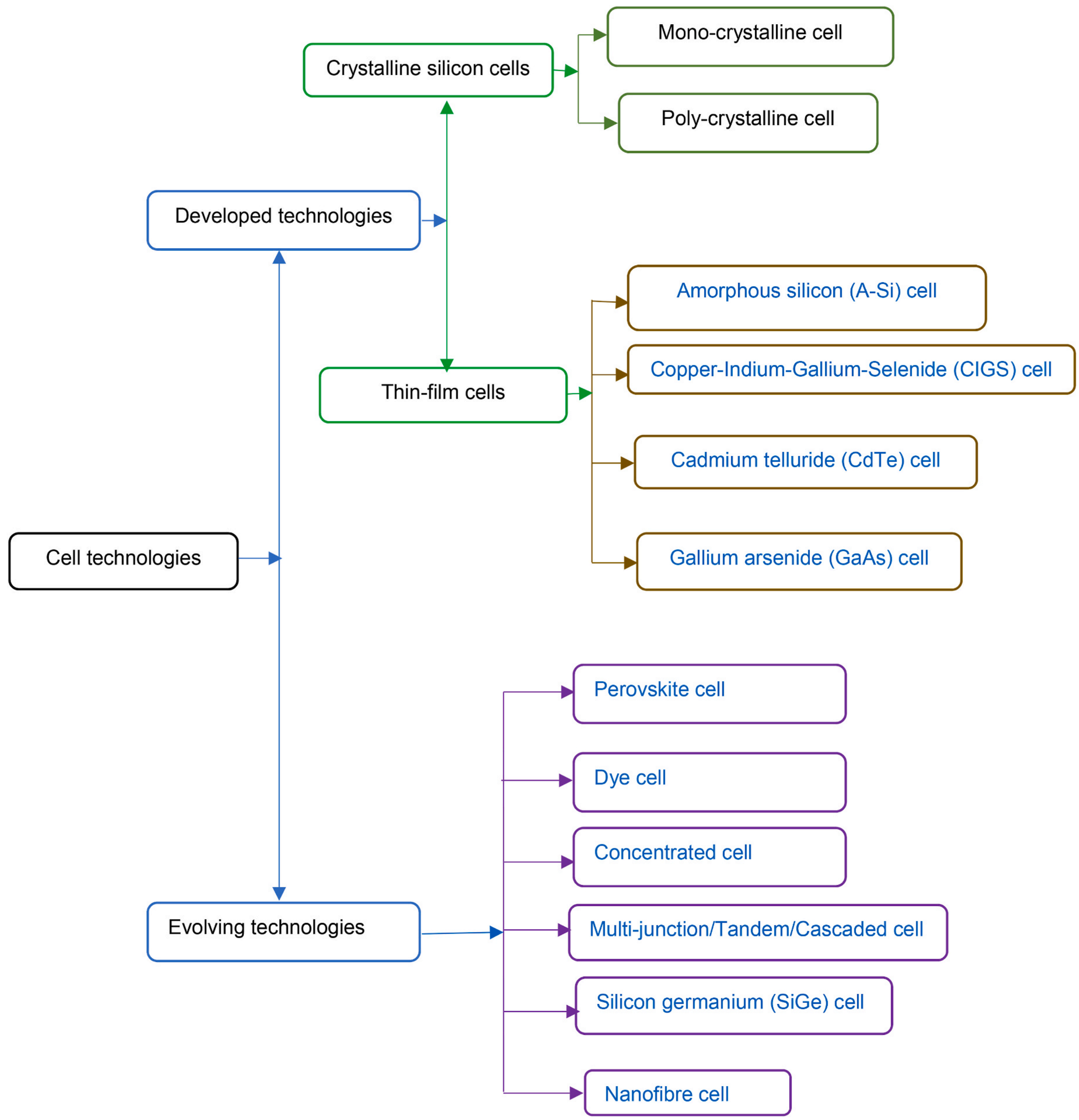

Fig. 1. Classification of PV cell technologies.

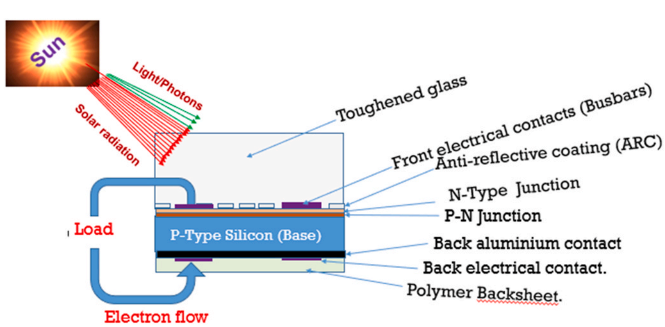

Fig. 2. Basic architecture of a *P*-type c-Si PV cell.

absorbed by the crystalline silicon in the module to produce the thermal energy while the visible and ultraviolet rays are converted to electrical energy by the module. The thermal energy increases the temperature of the module causing cell cracks, increased electrical resistance cum reduced electrical performance of the module and other associated damages. The heat energy can be harnessed by solar PV thermal and other associated technologies to provide hot water and heating. The produced electrical energy is used to power systems which include automobiles, water pump, lighting system, traffic lights, buildings, appliances, satellites, space vehicles, communication systems, etc. The critical component of a c-Si PV system used in powering a house or supplying energy to a net-work is shown in Fig. 4 and also reported in Ref. [15]. The incident visible and ultraviolet rays are converted to direct current (DC) by the module. The DC is feed into a charge controller. A DC output from the solar charger is used to power DC appliances including a light bulb. On the other hand, it can be stored in a battery and retrieved when needed to feed into an inverter. The inverter converts it into an alternating current (AC) which can be used to power a home or fed into an electrical network.

In terms of economics and technology penetration, PV has demonstrated dominance over all new global renewable energy (RE) investments, currently. Its market share is 48% of $139.7 billion invested in 2018. The market was circa 680 GW in 2019; projected 4767 GW by

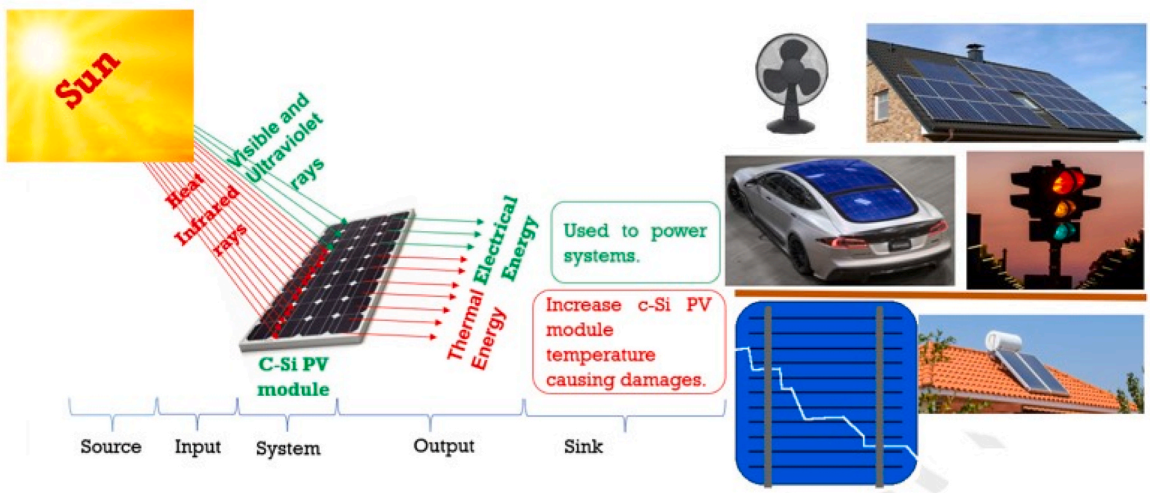

Fig. 3. Basic principle of operation of c-Si photovoltaic (c-Si PV) module.

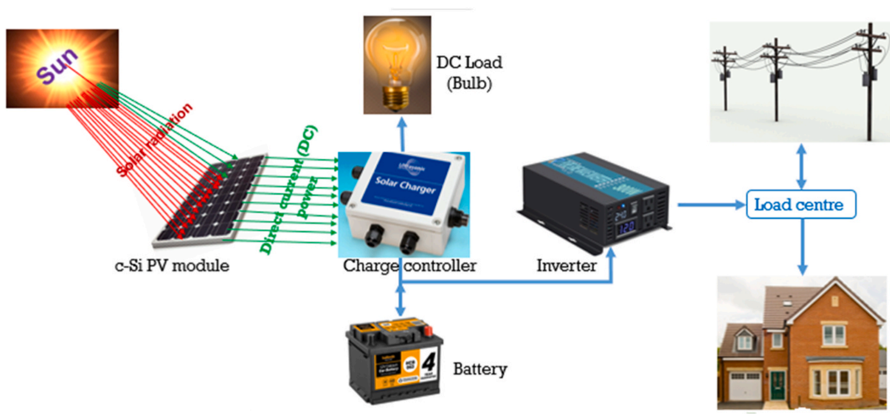

Fig. 4. Critical components of photovoltaic system [15].

2026. EU investment in 2018 was 11.3 GW – representing 21% increase from 2017. Fig. 5 presents the global renewable energy jobs in four key technologies within 2021 and 2022. Evaluating data from several reports including [16–20], Figs. 6 and 7 are plotted. Fig. 6 shows jobs in SE, wind energy (WE), hydro energy (HE) and geothermal energy (GE) from 2015 to 2040 in sets of six years. Similarly, Fig. 7 demonstrates the evolution of global solar energy job from 2010 to 2021.

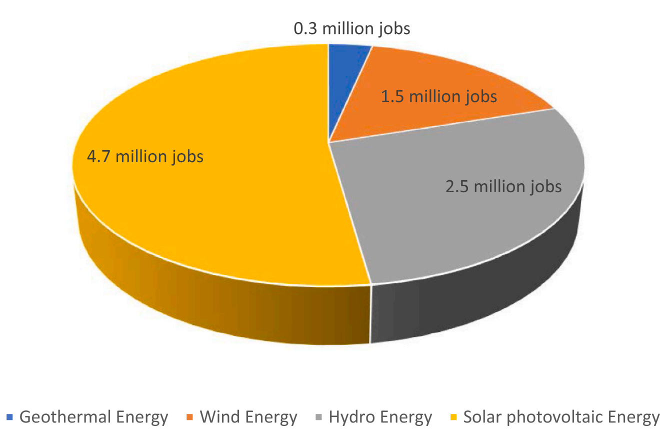

Fig. 5. Global renewable energy employment for four key technologies for 2021–2022.

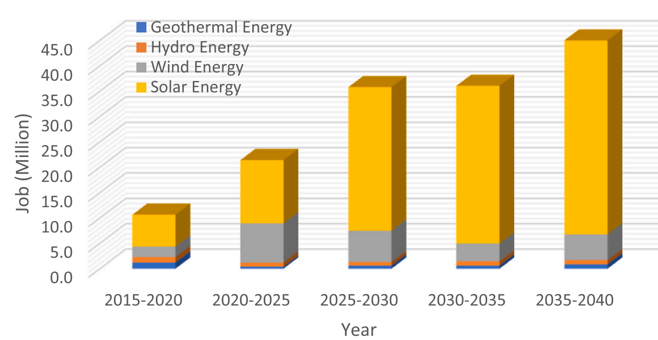

Fig. 6. Estimated employment opportunities in four key renewable energy sectors in Europe from 2015 to 2040.

The statistics represented in Figs. 5, 6 and 7 show that the worldwide jobs in the SES in 2022 is circa 4.7 million which aligns with earlier report from Ref. [18] that in 2021 global SES jobs is about 4.29 million with all renewable energy jobs amounting to circa 12.7 million. These statistics demonstrate a 5.83% growth from the 12 million recorded in 2020. It is deduced from Ref. [18] that China accounts for about 42% of the total while the European Union and Brazil constitute 10% each and are in the second position. United States and India occupy the third place with each contributing 7% of the total. China leads with a record amount that is just below 2.7 million, followed by United States at about 0.25

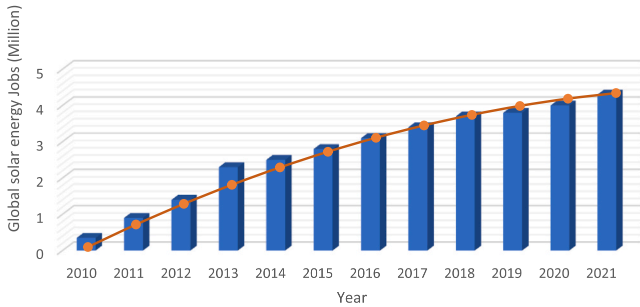

Fig. 7. Evolution of global solar energy job from 2010 to 2021.

million and India in the third place with approximately 0.21 million jobs. Fig. 6 presents estimates of employment opportunities in four key renewable energy sectors in Europe from 2015 to 2040 at interval of six years. Solar energy jobs are the most and are predicted to evolve consistently. The jobs in wind energy are presented second in availability. Analysis of the evolution chart presented in Fig. 7 indicates that the employment in solar PV sector has demonstrated significant monotone increase from the preceding year since 2010 and constitutes 33.86% of 12.67 million jobs in the renewable energy sector in 2021. This statistic show that the sector leads as the fastest-growing renewable energy sector – an indication of the positive rate of adoption of the technology. A quadratic line shown in the figure is used to predicts the job evolution.

However, without undermining the promising figures, a deduction from Ref. [21] that solar PV contributes about 15% of final energy consumption demonstrates the need to create more awareness on the huge potential of the evolving technology and sector towards the provision of global energy supply. The call is critical considering that [22] stated that approximately four million exajoules of SE with significant harvestable percentages reaches the earth annually and [22,23] reported that theoretically, SE possesses the potential to adequately fulfil the energy demands of the entire world if technologies for its harvesting and supplying were readily available.

Fundamental to achieving the technological needs of the solar PV industry to match the sector projected growth as evident from the preceding discussion is the availability of sufficient skilled personnel. Substantial amount of skills gap in qualified and training labour is reported across Europe and has driven numerous research including [24–28] on addressing skills gap and needs in the renewable energy sector around the world. The bridging of the skills gap is envisaged to be tackled by the universities, feeder colleges and academic institutions. The educational institutions ought to be embedding essential Solar Energy Technology Training (SETechTra) modules and courses in the undergraduate curriculum. Such modules and courses should be designed to inculcate critical solar PV skills in the STEM and STEAM undergraduate students. Creation of awareness on the skills gap, discussion and presentation of SE in-demand skills and the development of such training material are the focus of a recent Erasmus + project reported in parts in this article. This study outlines the critical skills needs of STEM/STEAM graduates which they ought to acquire to increase their employability and entrepreneurship in the SE sector. It also discusses the challenges Science, Technology, Engineering, and Mathematics (STEM) and Science, Technology, Engineering, Art, and Mathematics (STEAM) graduates face in securing jobs in the SE sector. The review achieves its aim through five objectives which include study on (i) solar energy technology sector specialist skills, (ii) educational needs, skills and challenges, (iii) industrial needs, skills and challenges, (iv) entrepreneurship needs, skills and challenges, (v) the need for solar energy technology training (SETechTra) module for STEM/STEAM undergraduates/graduates.

2. Solar energy technology sector (SETS) specialist skills

As demonstrated, the SES is experiencing significant growth both nationally and globally – leading to increasing penetration of the technology and offering a wide range of jobs in different areas including manufacturing, deployment, consulting, construction, installation, operation, maintenance as well as research and development. According to Ref. [18] solar energy related job accounted for almost 40% of global renewable energy related employment in 2021. To sustain the technological advancement the sector requires different types of specialist skills personnels that covers the entire value chain, from laboratory scale researchers to component manufacturers, system's construction and installation, engineers, and technicians.

2.1. Skills needed by the solar energy (SE) industry

Diverse employment opportunities ranging from technical to business and regulatory positions are currently available in the solar energy technology (SET) industry. As the sector continues to grow, new job profiles and opportunities are poised to emerge. Therefore, there is a necessity to review skills need of the industry to match both the current as well as projected demand of the sector. Based on the findings of this extensive review, the skills needs are vast. However, good attempt is made in discussing critical skills which include cell and system design, module manufacturing, research and development, project approval and documentation, system design and construction, installation and commissioning, consulting and marketing, and operation and maintenance. Cell and module manufacture focuses on the production of the components of a cell, their assemble into a cell, and then the cell assemble into a PV module. Skills in the operation and maintenance of equipment used in the production process are needed. Additionally, manufactured modules and system are tested against established standards - predominantly International Electrotechnical Commission (IEC) Standards. Thus, skills related to quality control of the components and systems are needed. System design, construction, installation, commissioning, and management of the process is usually carried out in one subunit. A detailed design of the system is carried out in the design phase. This includes determination of the location of the system. System is sized based on the load requirement and estimated production yield of the site based on the rating of the PV module, system and field. Critical system's components as displayed in Fig. 4 are selected and their specification are computed. Substantial knowledge of government regulations and skills in ensuring system compliance is required. In-demand is also skills to work closely with clients to understand their needs, provide recommendations and design their needs into the system for optimal system operation and reliability. Other skills include project management involving planning, design, construction, and commissioning. Specialised technical skills from fields which include civil, mechanical, and electrical engineering are needed. More advanced skills are required at the graduate level which is expected of an engineer, while lower skills are needed from technicians and craftsmen.

Fig. 8 shows the critical process stages (a) to (h) in the technology deployment including system construction and installation. It is PV system integration into buildings at the Satakunta University of Applied Sciences (SAMK), Finland. The skills required in each stage of the technology deployment are discussed in subsequent sections. As demonstrated in Fig. 8, the (a) shows staff engaging in material handling, the (b) and (c) present personnel in ridge base construction. The (d) and (e) depict advancement to truss construction and module attachment. In (f) the electrical personnel are wiring the module as desired. The connected modules which form system are portrayed. The civil and mechanical technicians cum engineers are involved in the stages depicted in (a) to (e) while the assemble and connection of the panels in stages (f) to (h) are carried out by electrical engineers and technicians who must adhere to necessary safety procedures. The job skills in-demand in building a foundation of PV solar tracking system is

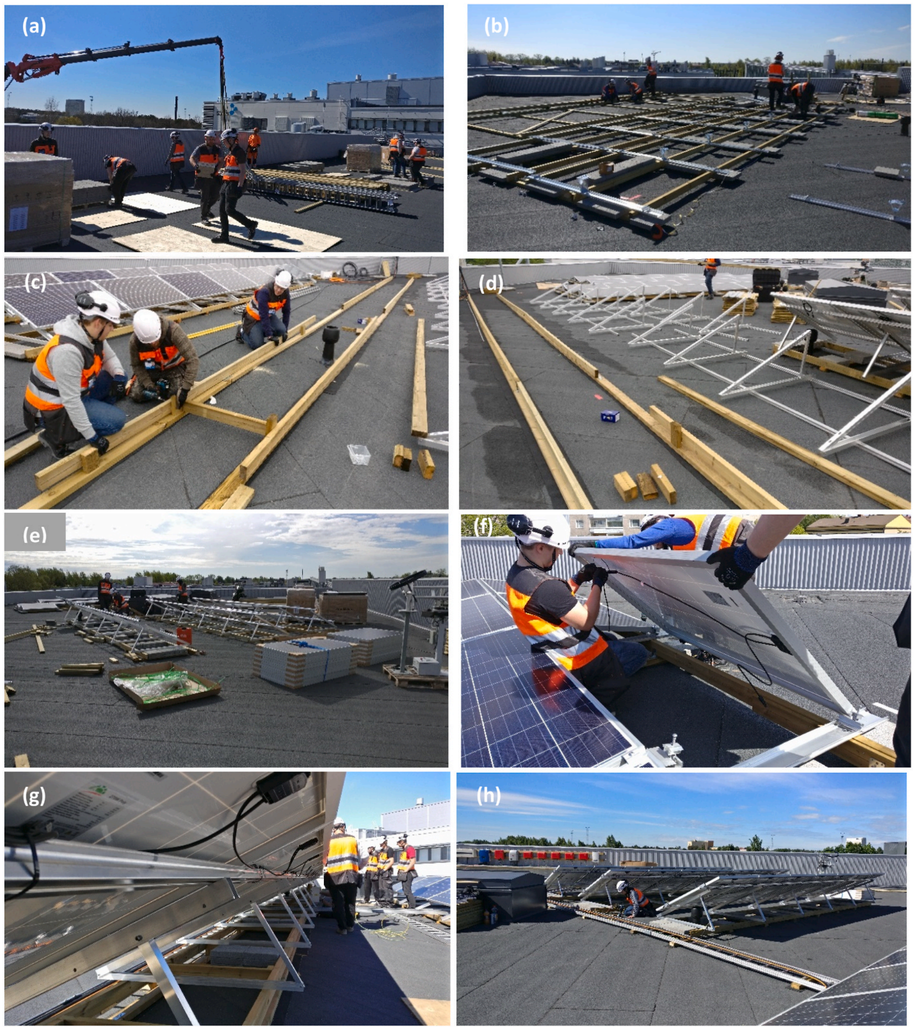

Fig. 8. Critical process stages in PV system deployment including construction and installation.

predominantly civil engineering. Fig. 9 presents a PV system with solar tracker – showing its foundation and complete operational system in (a) and (b), respectively. Skills in the design and development of solar tracking system is on the rise owing to several advantages. It supports optimisation of system production efficiency leading to more energy yields and fast-tracking of return on investment. Operational PV systems require routine maintenance of the whole system as well as its sub-units. These requirements put associated maintenance and fault-finding skills in demand.

Solar energy (SE) consulting and marketing activities are vital elements of the sector. Consulting skills are required to provide expert advice and guidance to clients who are considering SE as an option. Key components of these skills are energy consumption analysis, projected savings from the use of SE, advisory reporting on best available solar technology products and conceptual design services. Ability to analyse and interpret data relating to energy production and consumption cum cost savings carried out using simulation tools that predict system performance is needed. These are varieties of sector in-demand consultancy skills. Like any other system, operating PV system must be routinely maintained. Skills in cleaning, replacement of faulty PV module, system components, and system fault troubleshooting are in increasing demand. SE marketing requires other skills and qualifications that do not necessarily draw from STEM subjects. These skills may be inclined more to selling SE products and services to individuals and industries. However,

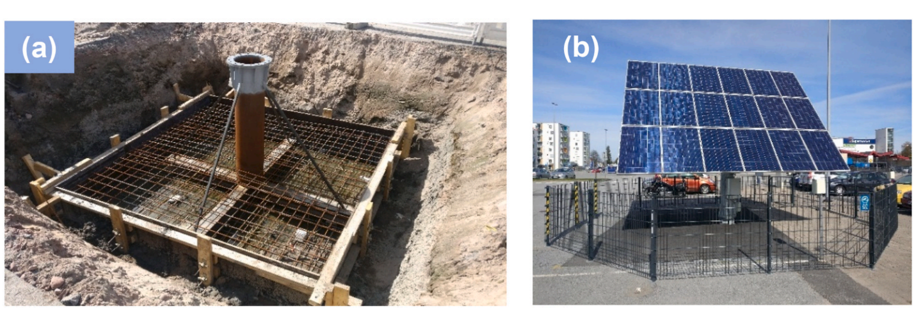

Fig. 9. PV system with solar tracker - (a) system foundation (b) complete operational system.

significant knowledge on solar technology, energy, and economy is needed to execute the job, successfully.

Fig. 10 presents a structural classification of in-demand skills set in the SES. It depicts academic, industrial, and entrepreneurial skills as the three key skills. Furthermore, it categories industrial skills into manufacturing and deployment skills and argues that academic skills are skills acquired through education and mostly via degree programmes. Degree in several engineering fields including energy system, chemical, materials, electrical, electronics, industrial, mechanical, civil and software stands out. Some other skills are acquired through degrees in physics, renewable energy, business administration, sustainable technologies, marketing, management, solar PV installation, power plant

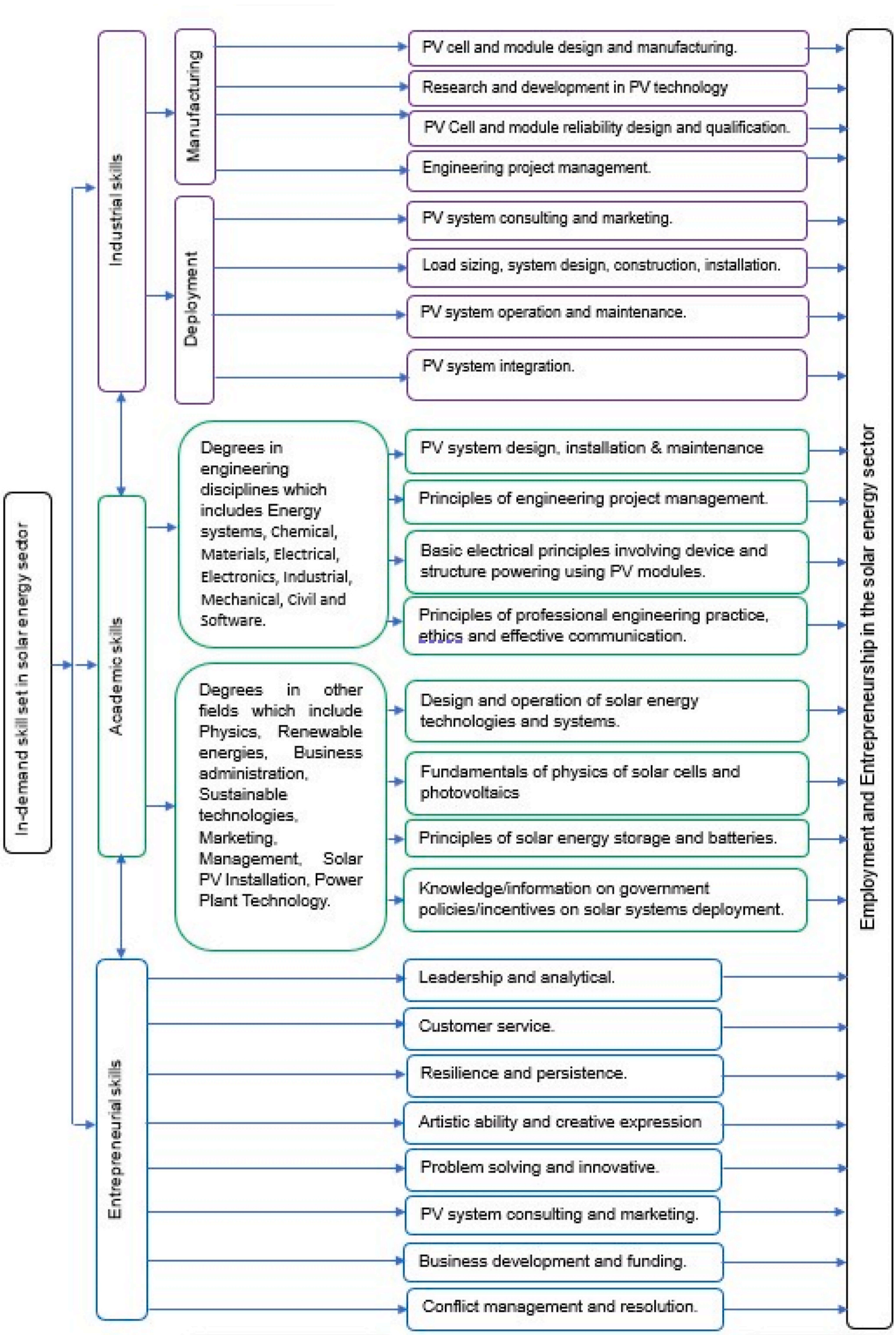

Fig. 10. Characterisation of in-demand skills set in the solar energy sector.

technology. Entrepreneurial skills are observed to have strong dependence on degrees from other subject other than engineering and technology. Fig. 11 depicts the Venn diagram representation of the three critical in-demand skills whilst portraying the commonality and intersection of the skills. It shows that science and technology of PVM, project management as well as marketing and consulting are common among the key skills of academic, industrial, and entrepreneurial skills. To support the sector to access the required skills in the current accelerated growth, awareness on the sector skills needs ought to be created, urgently.

2.2. Awareness creation on solar energy sector (SES) specific skills

Although solar energy (SE) is one of the fastest-growing sectors, observations demonstrate that lack of awareness on the specific skills needed by the sector exist. Studies including [29] reported on mismatch between skills produced by the academia and the skills in-demand by the sector. Universities and feeder colleges are deemed to be the vehicle to be used to salvage this undesirable development. It is theorised that the academia can do more in these regards by incorporating study visit, guest lectures from SE companies, internship, career fair, newsletter and other relevant activities in the related solar technology modules they offer at both the undergraduate and graduate levels. During the fair, representatives from different stake-holder companies can be given the opportunity to interact with students/leaners in person. The recognition that many solar energy technology (SET) companies are continuing to offshoot indicates the need for targeted awareness creation on specific skills needed by the sector to match future demands on skilled labour. It is anticipated that as the sector develops with diversification in new applications, careers in the field will continue to evolve. Explicit discussion on educational skills needs and challenges are presented in subsequent section.

3. Educational needs, skills, and challenges of SETS

A review of solar PV module in the USA in 2023 reveals the top 10 PV brands and their manufacturers. A USA company ranks the best and the country dominates solar PV production. North American, Norwegian, Shanghai, South Korean, and Chines companies ranked second, fourth, sixth, ninth and tenth, respectively – with no EU company recorded. Inference is that the EU SE sector has not demonstrated possession of significant robust sector skills which are globally competitive. Assertion can be linked to skills mismatch between availability and need, already reported. The skills gap ought to be narrowing by producing more sector specific skilled labour if adequate support is to be given to the EU circa 50% increase in installed capacity in 2021 to 41.4 GW towards the delivery of Net Zero by 2050.

The production is critical considering that the European Union (EU) has emphasized on increasing use of renewable energy, including solar energy (SE), as part of her efforts to reduce greenhouse gas emissions and transit to a low-carbon economy. To fast-track the transition, three strategies are proposed. These are development of targeted curriculum in Education and Training (E&T), expansion of STEM curriculum to include STEAM, and development of resource pack.

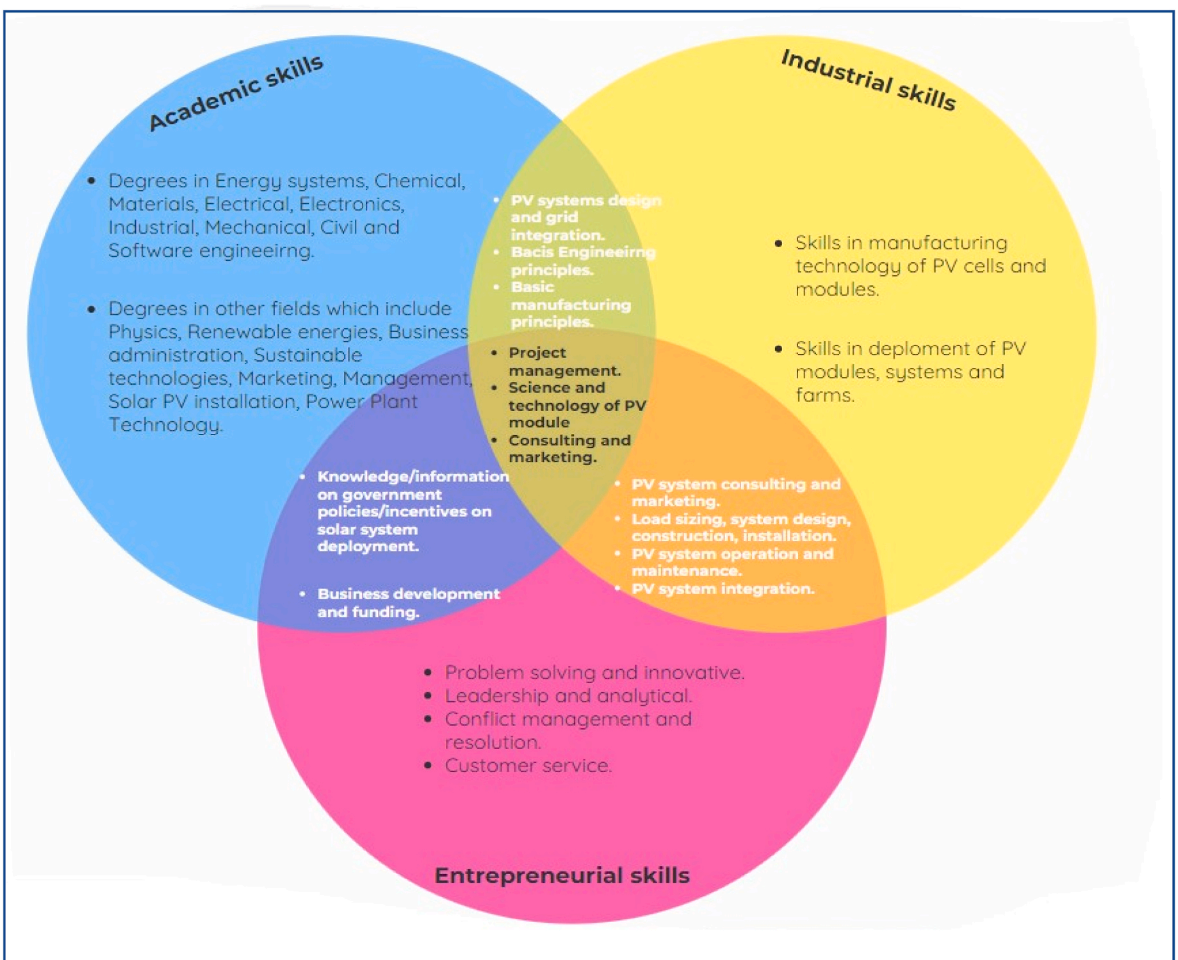

Fig. 11. Venn diagram representation of three critical in-demand skills in the solar energy sector.

3.1. Targeted curriculum

Based on extensive review, targeted curriculums are deemed one of the appropriate means to achieve the production of more STEAM students with appropriate SES in-demand skills. The curriculum should be developed to provide specialised education focused on development of critical skills needed to tackle skills gap challenge currently in the solar technology sector. Academia should be designing and offering education and training (E&T) courses in the SE technologies that target both professionals and non-professionals in the fields.

The professionals are identified as STEM undergraduate students, solar technologies educator, PV module and system installers, technicians, and engineers. Curriculum contents for this set should be mainly technical – drawing from fundamental knowledge on STEM. The focus should be supporting the professional to deepen their knowledge and understanding of the operations of photovoltaics as well as other energy systems as rooted in electrical engineering and associated disciplines. The contents should also include specialised topics on photovoltaics system design, installation, maintenance, project management, professional and communication skills. With reference to an anticipated global adoption of PV system in building, the curriculum contents must incorporate applications to both new and existing buildings with a focus on the technical requirements and best practices. Professional and communication skills should be designed into the curriculum to inculcate both good practice and communication skills to the learners as they will utilise the skills to effectively discharge their duties within the EU. For the STEM students interested in solar energy technologies (SETs), the curriculum contents should include a range of courses that provide a solid foundation on the principles and technologies of SE. These courses should include topics on the fundamentals of photovoltaics, including the physics of solar cells, the design and operation of SET systems, principles of SE conversion, SE generation, transmission, utilisation, and storage. It should also provide opportunity for the student to learn how the solar materials and cells convert photons in sunlight into electricity. For the educators, a special curriculum should be designed to provide them the opportunity for professional development. The short course should consist of how to develop lesson plans, delivery materials and other relevant resources. For the installers and technicians, universities, colleges and academic institutions could design and offer a 2-year degree apprenticeship and short courses in SET. These programs will offer them the opportunity to technically upskill in the latest and state-of-the-art technologies in the sector. Additionally, it will provide them the platform to update their knowledge on government regulations, and best practices in the field.

The non-professionals are identified as pupils, young adults, policy makers, decision makers, homeowners, property owners, business owners, organisation CEOs, farmers and rural community dwellers, as well as project managers. For this set, their targeted curriculum contents should include bespoke topics on subjects on information and awareness, solar project financing options, SE system components, sizing, and maintenance. The focus of the topic on information and awareness should centre on benefits of solar technology adoption as well as the potential of solar energy. This should be extended to environmental benefits, government incentives, rebates and system payback time. In addition, it should contain topic on knowledge sharing on policies and regulations that support solar system deployment. It is also imperative that the contents are designed to support the set to upskill in system sizing, logistical considerations, system routine maintenance and parts replacement. Application of the contents should be specific on the needs of categories within the group. Inclusion of pupils and young adults in this group is important considering that security and sustainability of skills in the sector has become a concern and recognising that awareness creation of the skill set in-demand in the sector to the pupils and young adults will orientate their minds early. These are the future workforce. A curriculum which targets to educate policy makers, decision makers, and other stakeholders to increase their understanding of the benefits and potential of SET, as well as the policies and regulations that support its deployment is desirable for increased technology penetration. It is anticipated that wider SET penetration will be achieved if the policy makers, decision makers, homeowners, property owners, business owners, organisation CEOs obtain relevant information and essential training on the technology – achieved through informed curriculum contents.

From the forgoing discussion, there is a wide range of educational needs and positive impact the academia can make in terms of designing and running targeted curriculum which will bridge the skills gap in the sector in the EU. For greater impact, curriculum expansion of STEM to STEAM is advocated for increased production of sector skilled workforce to match anticipated sector growth.

3.2. Curriculum expansion of STEM to STEAM and its implementation challenge

Discipline-based education is a traditional form of educational system. In the context of STEM, these disciplines are typically skills in sciences, technology, engineering, and mathematics. This traditional model of education produces experts in these specific knowledge [30]. Expanding a STEM curriculum to include Art subjects (sciences, technology, engineering, arts, and mathematics) is designated STEAM and it implies enriching STEM subjects with arts for all inclusivity. Studies have shown that with the inclusion of arts and creativity - enabling expansion of STEM to STEAM – more students and learners have demonstrated long-term interest and engagement in science education [31]. Research [30] also shows that adding social sciences to technical training prepares future leaders to creatively participate in solving known barriers towards a sustainable society. It is proposed that for all inclusivity within the sustainable SES, the STEM curriculum will have to be expanded to STEAM. This is necessitated on recognition that STEM professionals like engineers, scientists, and educators will have to work with STEAM professional such as project managers, policy makers, and marketers in the sector. The vast needs of the latter specialists increases the need for the presence of arts in the future education of STEAM disciplines [30]. To expand the curricula from STEM to STEAM, an essential part is to create a social space and environment where the students and learners can develop skills in creativity and imagination as well as make mistakes [31]. Key expansion steps include assessing of current curriculum, reviewing of existing STEM curriculum, identification of areas for arts integration to provide new perspective, and enhancement of learning experience. The steps are drawn with knowledge that STEAM is reported by Ref. [32] as a cross-curricular collaboration. Essentially, the processes involve collaboration with arts educators and teachers to integrate artistic concepts, such as design thinking, into STEM subjects focused on delivery of skills needs in SES. In new teaching method development, it is important that the teachers involved are team players willing to co-plan and co-teach [32]. Incorporating creative problem-solving and design thinking in the curriculum supports students and learners to develop soft skills [33]. Encouraging students and learners to approach STEM problems with a creative mindset and providing opportunities for them to express their solutions through various art forms are found effective. The ability to solve problems is one of the most important thinking/soft skills [33].

While delivering SE contents, utilisation and integration of technology and digital media into the curriculum will support the learning of STEAM students. Alternating traditional teacher-centred lectures focused on the possibilities for students with autonomously acquire knowledge in digital platforms with the freedom of choice of time and learning method is a practical example of utilizing technology to add creativity [31]. With regular evaluation of the effectiveness of a STEAM curriculum, area of adjustment for increased and sustained STEAM engagement can be identified. Adoption of STEAM approach provides the opportunity for non-science students and other under-represented/minorities who are interested in career development in

SETs to realise it [30]. This is more so as enhancing STEM topics with arts creates more attractiveness to STEM subjects [31]. By integrating the arts into STEM education, students are exposed to a wider range of problem-solving approaches and can gain a deeper understanding of how STEM and the arts intersect and complement each other for more sustainable SETs skills production.

STEAM education has been acknowledged as a beneficial approach to enhance student learning in convergent thinking, creativity, and character development [34]. However, the implementation of STEAM in classrooms faces challenges because many educators have an over-simplified understanding of STEAM as a series of activities rather than a holistic approach to learning [35]. Many STEM educators feel unprepared to foster transdisciplinary skills in their students due to a philosophical conflict. Thus, STEM education has always focused on objective knowledge, while transdisciplinary skills require a subjective approach [36]. Furthermore, it is found that educators who participate in semester-long STEAM course struggle with interdisciplinary integration leading to some difficulty in collaboration across disciplines with significant increase in workload and scheduling conflicts [37]. Specifically, the "Art" components of STEAM curriculum integrate the human element which prepares graduates for successful entrepreneurial career in the SES. It encompasses creativity, co-operation, self-awareness, commitment, and self-esteem [38]. While technical skills are undoubtedly important, it is the integration of the "Art" domain that largely determines the quality of a graduate's training. This domain equips graduates with the ability to collaborate effectively and market their products successfully [39]. Employers seek graduates who can adapt to new situations and driving change. They expect their employees to take charge of their own professional growth - indicating that organizations are potentially hesitant to invest in enhancing their employees' skills [40]. Technical skills are found to only account for 30% of the factors that helped people secure employment in multinational corporations [41] including the SE sector.

3.3. Resource pack

Unlike the targeted curriculum, resource pack is designed for self-study focused on supporting any interested individual at any level to develop the solar energy sector (SES) in-demand skills. The pack is a handy portfolio of information, materials, and activities relevant to acquisition of SE skills. Good resource pack contains step-by-step guidelines on installation, energy generation, maintenance, safety considerations and best practices of SE systems. Moreover, at advanced implementation, it contains topics on system design and planning with tools that support learners to plan and design SE systems for different applications. The tools include design software. There are several software and other design tools available at free access, pay-per-view and lease or bought out licenses. The pack should present real-life examples and case studies of successful SE projects to demonstrate practical applications of the tools to SE. This offers the opportunity for learner to compare and evaluate their own designs with the real-life examples. In addition, it should contain automated self-assessments and quizzes that support trainees to assess their knowledge and understanding of the contents of the resource pack. The automation of the assessments makes them not bound to time or place. For continuous learning, the resource pack should provide a collection of reference materials, such as technical manuals, standards, guidelines, and publications that trainees can use to continue their learning and keep up to date with the latest developments in the sector.

A good pack contains information by EU countries on specific education and training (E&T) required to work in the SE industry in the EU countries. It is imperative to note that some countries require a degree in a relevant field such as engineering, renewable energy, physics, energy systems engineering, energy conversion engineering or even a professional certification.

3.4. Institutions in four European countries with courses they offer in solar energy technology/engineering

To estimate the current impact of institutions in four European countries in the production of STEM and STEAM graduates with SES in-demand skills, a review of the courses/programme they offer in solar energy technology/engineering and related renewable and sustainable energies and technologies is carried out. While the review is extensive but not exhaustive, Table 1, presents the finding in UK, Finland, Greece, and Norway. It is observed that all the courses are at the postgraduate level with MSc accounting for 94.89% and both MEng and MA constituting 2.56% each. The finding that all the courses are at the masters' level and recognising that Master's degree holders are comparatively smaller than the First degree holders, may explain why more needs to be done by the EU HEIs in this regard. The table also shows fewer number of course in the SET and engineering in comparison to associated courses in renewable energy and energy engineering in general. It also demonstrates the need for the EU HEIs to develop and run more specialised course tailored to producing graduates with the SE industry -in-demand skills.

As it is theorised that EU educational institutions ought to be doing more in producing STEM and STEAM graduates with SES in-demand skills such as solar PV system design, installation, and maintenance as well as additional soft skills which include project management, communication, and teamworking skills if sustainability of the SES is to be achieved, a completed review of the sector in-demand industrial skills is critical to ensuring that the design of the targeted curriculum/module is comprehensive.

4. Industrial needs, skills and challenges of SETS

The exponential growth rate in the demand on renewable and solar energy in recent years has been reported by many researchers including [42,43]. Europe is the continent with the highest adoption of solar power at an average of about 4% of its electricity demand. This statistics translates to markets share of about 8% - a level unmatched by any other region [44]. Moreover, Europe has demonstrated a significant increase in installed solar power capacity from 130 MW to 110 GW - leading to an increase in annual electricity generation from 90 GW h to 120 TW h. An analysis of solar power development in Europe reveals that Germany, Italy, and Spain follow a logistic growth path with saturation levels proportional to their GDP. France, UK, and Belgium show a similar pattern with a time lag relative to the first three countries. These two groups together account for 85% of the solar power development in Europe [45]. As a direct impact of the development, the global solar energy industry (SEI) has experienced significant growth in recent years, with the concentrated solar power (CSP) sector projected to have a global installed capacity of up to 100 GW by 2025, creating approximately 100,000 to 130,000 new jobs. Of these job positions, around 45, 000 are expected to be permanent full-time roles in operations and maintenance [46].

However, working in the SE industries requires possession of specific technical skills including expertise in PV module roofing [47]. The increased demand on SE has led to a high demand of skilled professionals such as engineers, project managers, and data analyst in the industry because all the skills need of the sector cannot be fully met by the available workforce. Specifically, it is observed that experienced skilled labour in SE integration to the grid is limited. As the performance of the technology directly depends on weather conditions, high initial installation cost has become a concern [42,48] necessitating the demand for more professionals who can provide expert advice to stakeholders considering SE option. Although the cost of PV cells has continued to decline steadily over the past years, the initial cost of installing SE systems and cost of electricity produced from PV systems is still relatively high [42]. This can be a barrier to adoption, particularly in the developing countries and for low-income households, where the average

Table 1
Some institutions in four European countries and courses offered in Solar Energy Technology/Engineering.

S/N	Country	Institution	Degree	Programme/Course
1	United Kingdom (UK)	Teesside University	MSc	Sustainable Energy and Clean Technology
2		University of Sheffield	MSc	Solar Cell Technology
3		University of Exeter	MSc	Renewable Energy
4		University of Nottingham	MSc	Renewable Energy and Architecture
5		University of Aberdeen	MSc	Renewable Energy Engineering
6		Northumbria University, Newcastle	MSc	Renewable and Sustainable Energy Technologies
7		Coventry University	MSc	Renewable Energy Engineering
8		Loughborough University	MSc	Renewable Energy Systems Technology
9		Imperial College London	MSc	Sustainable Energy Futures
10		University of Warwick	MSc	Sustainable Energy Technologies
11		University College London	MSc	Materials for Energy and Environment
12		University of East Anglia UEA	MSc	Energy Engineering with Environmental Management
13		University of Liverpool	MSc	Energy and Power Systems
14		Northumbria University, Newcastle	MSc	Renewable and Sustainable Energy Technologies
15		Kingston University, London	MSc	Renewable Energy Engineering
16		Robert Gordon University	MSc	Renewable Energy Engineering
17	Finland	Aalto University	MSc	Energy Conversion Processes - Advanced Energy Solutions
18		LUT University	MSc	Sustainable Energy System
19		University of Oulu	MSc	Environmental Engineering - Sustainable Energy Systems
20		University of Helsinki	MSc	Environmental Change and Global Sustainability
21		Tampere University	MSc	Technology, Sustainable Urban Development
22		Savonia University of Applied Sciences	MEng	Energy Engineering
23		University of Vaasa	MSc	Sustainable and Autonomous Systems
24		Abo Akademi University	MSc	Sustainable Chemical and Process Engineering
25	Greece	National Technical University of Athens	MSc	Energy Production & Management
26		National Technical University of Athens	MSc	Energy management and environmental protection
27		National Technical University of Athens	MSc	Environment and Development
28		Technical University of Crete	MSc	Sustainable Engineering and Climate Change
29		University of Thessaly	MSc	Sustainable Management of Environmental Change and Circular Economy
30		University of Thessaly	MSc	Analysis and Management of Energy Systems
31		University of The Aegean	MSc	Global Environmental Change, Management & Technology
32		University of Western Macedonia	MSc	Renewable Energy Sources & Energy Management in Buildings
33		University of West Attica	MSc	Energy
34	Norway	Norwegian University of Science and Technology	MSc	Sustainable Energy
35		Norwegian University of Science and Technology	ME	Energy and Environment
36		Norwegian University of Science and Technology	BE	Renewable Energy
37		Norwegian University of Life Sciences	ME	Environmental physics & Renewable energy
38		Norwegian University of Life Sciences	BE	Renewable Energy
39		University of Oslo	MSc	Renewable Energy Systems
40		University of Bergen	MSc	Sustainability
41		University of Agder	MSc	Renewable Energy
42		University of Agder		University of Agder
43		University of Stavanger	MA	Energy, Environment and Society
44		University College of Southeast Norway	MSc	Energy and Environmental Technology

income per hour is less than $1. The studies by Refs. [42,48] agree that cost, manufacturing procedure, and waste products are some of the fundamental challenges facing further penetration of SE systems. This is critical as more countries position themselves to adopt the technology. Consequently, the industry has encountered difficulties in finding qualified labour for these roles, leading to a growing call for HEIs to produce more graduates that possess industry in-demand skills.

The call is strengthened by the observation of current trends and developments in the SEI. The SE market is rapidly evolving, and the technology has witnessed considerable advances in trends and developments in the last decade. Key trends and developments are depicted in Fig. 12. Increased adoption of SE is among the current trends and development in the sector. The development is attributed to significant decline in the unit cost of the energy in recent years [49]. Solar energy from PV module and systems has become more affordable and thus attractive to consumers and businesses. The study by Ref. [49] on 287 Italian citizens reported that 85% expressed a favourable disposition about a potential installation of SE system. Similarly, outcome of study by Ref. [50] shows that 71.6% out of 310 respondents chose to adopt renewable energy as a source of electricity generation.

To accelerate SE adoption and penetration, governments are enacting favourable policies which offers incentives and subsidies. It is observed that the technology has achieved significant advancement in that respect. The research reported in Refs. [43,51–53] reported on some of the improvements in the technology including solar module manufacturing, module/system efficiency as well as energy storage solutions. Specific advancement are in the area of new technologies that include bifacial solar panels, organic solar cells, perovskite solar cells, thin-film solar cells, dye-sensitized solar cells (DSSCs), as well as developments in materials science and engineering [43].

There has been a growing demand for energy storage in the renewable energy industry in order to strengthen power networks and maintain load levels [54]. The significant contributions of SE and other types of renewable energy source have made this demand crucial because the energy generated from different sources can be used when required [55]. Several authors including [54–57] have documented various forms of energy storage systems. The findings from these authors proved that the deployment of batteries and flow cells are becoming increasingly

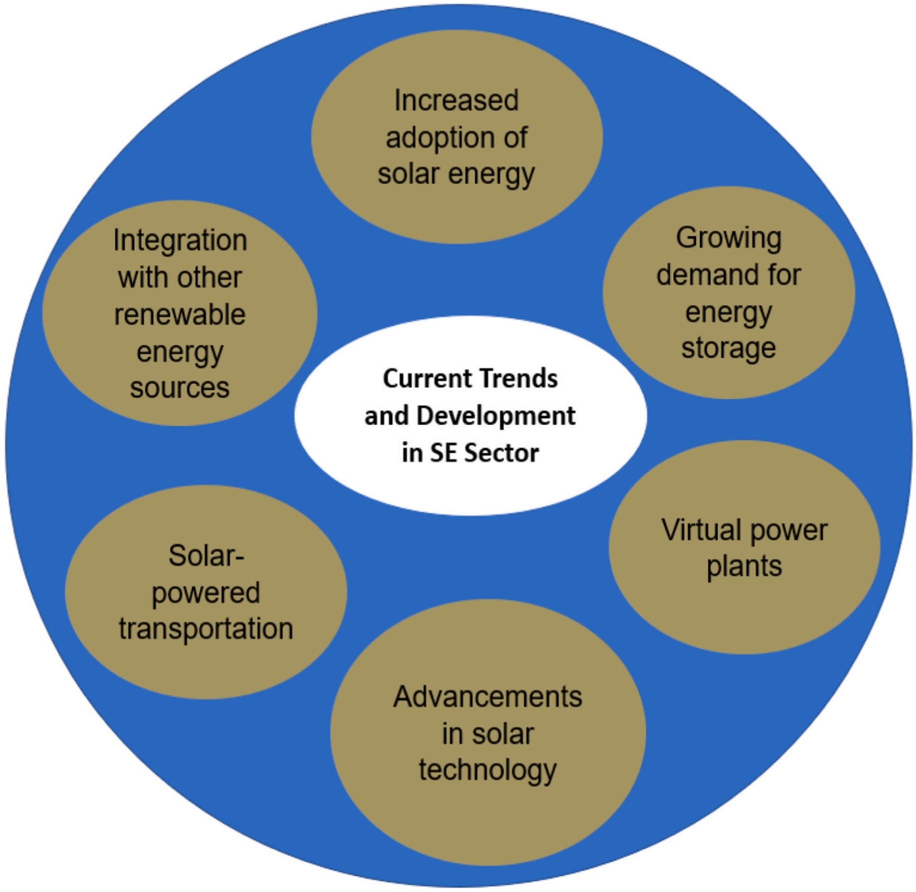

Fig. 12. Current trends and developments in the SE Industry.

efficient and cost-effective. To provide backup power, solar batteries, inverters, and charger controllers and integrated into the PV system. This enables SE to be stored and used when sunlight is unavailable. Utilizing an energy storage system can help to significantly lower energy costs, while providing more dependable and secure power to use for a longer period. The energy industry has achieved landmarks in Virtual Power Plant (VPP) with the integration of SE with other renewable energy sources including wind, hydro and geothermal energies. With this new trend, networks of energy systems are integrated and independently process numerous distributed energy resources, energy storage utilities, and loads, through a central control system, allowing them to function as a single power plant. The studies by Refs. [58,59] documented the challenges and opportunities in executing the newly emerging trends. The advantages of the new trends in the SES include improved overall energy efficiency, decreased waste, realisation of reliable and sustainable energy, and system cost reduction. Significant deployment of SE in transportation systems is achieved. Applications include power cars, buses, trains, ocean vessels, and many more vehicles. Researchers [60,61] presented the potential of application of SE systems for electrified urban transportation systems. The research by Ref. [60] shows that the SE could play significant role in the supply of traction systems.

Based on the developments and observations of current trend in the SE industry, it is projected that strong implementation of STEAM curriculum in tertiary educational institutions will produce sufficient skilled graduates to matching the surging demand of SEI specialist skills. However, proper implementation is advocated and can be achieved with deeper knowledge and understanding of STEAM curriculum development. Level and stage of deployment in the institution are a key factor. Yakman's STEAM Pyramid integrates STEM and arts, and recommends a practical STEAM program for middle schools to assist students in identifying career paths [62].

5. Entrepreneurship needs, skills and challenges of SETS

In the past 15 years, a new wave of development in the SET has emerged, driven by policies and regulations that support the growth of the industry [63]. In the recent years, the UK government like many governments offers incentives in the form of feed-in tariffs, which has been successful in encouraging more use of PV systems in households. However, some countries' governments have reduced the subsidies, which could potentially run counter to the policy's objectives leading to uncertainties on the effects on industrial stakeholders [64]. An extensive assessment of operational effectiveness of Chinese solar PV companies using global principal component analysis reported on the effect of cutting back on government subsidies [65]. It is observed that thriving of entrepreneurship in the SES has become a challenge following the dwindling government subsidies that has negatively impacted business growth and sustainability. Significant business growth is recorded from 2010 to 2020 in the global market for solar and wind energy technologies [66] offering many job opportunities to STEM and STEAM graduates - particularly in the SES. Current STEM education is found to focus more on first engineering principle [67], leading to production of engineering graduates who do not possess the necessary industrial and practical skills needed to address challenges in SETs owing to current curriculum comprising little contents on green design strategy [68]. Thus, it is proposed that STEAM curriculum incorporates socio-technical element with the objective to embed skills to manage complex relationship between technical and sustainable strategies in the students. It is theorised that the responsibility for addressing the skills gap in energy sustainability rests not only on external education and training institutions, but also on employers [69].

To address the entrepreneurship needs, skills and challenges in the SES, discussion on development of robust entrepreneurial ideas and sector in-demand skills are paramount. The discussion is presented in relation to the current dwindling government policies and targeting boost in production of graduates with the required skills set.

5.1. Entrepreneurship and government policy on solar energy sector (SES)

Entrepreneurs have a critical role to play in delivering UN sustainable development goal 7 and Net Zero by creating new solar energy (SE) businesses or other businesses that utilise solar energy and its technologies. However, it is observed that entrepreneurs encounter unlimited challenges in establishing successful SE businesses owing to government policies. Germany seems to have led Europe in adopting renewable energy policy in 1974, but appears to initially allocate modest government spending towards SE because they prioritised nuclear and coal production [70]. Britain's interest in SE was revived during the oil crisis. In 1976, the Department of Energy commissioned a study on the potential of SE, which predicted it could contribute 2% of the country's energy needs within 25 years if sufficient investment was made [71]. Nonetheless, the pace of progress slowed down as the exploration of oil and gas in the North Sea gained pace. BP, for instance, seems to have detected natural gas off the East Anglian coast in 1965 [70]. In 1980, the Italian national electric utility ENEL appears to construct the first large concentrating-type solar power plant in Sicily. Unfortunately, despite several years of testing, the facility was later shut down [72]. Clearly, the insufficient drive from the government to promote and support the SES has led to low level of interest among entrepreneurs in developing businesses in the sector. It is demonstrated that government policies are one of the key drivers of entrepreneurial growth in the SES.

In a survey of 60 entrepreneurs - from venture capital and private equity funds in Europe and North America – evaluating policies that could stimulate their desire to invest in novel clean energy technologies like the SE, feed-in tariff ranks high. It was found effective in promoting entrepreneur's interest to invest in emerging renewable energy technologies by diverse types of fund managers with distinct characteristics [73]. By offering an attractive feed-in-tariff promotion for the utilisation of PV SE, the overall energy cost can be reduced with increase in consumer demand. It is anticipated that unpredicted demand surge may lead to PV material shortage with attendant supply challenge. The study conducted by Ref. [74] found that the growth potential of PV technologies and their ability to sustain cost reduction trends in the future may be constrained by the availability of crucial materials. The observation is more critical considering that net zero drive has galvanised governments globally to give SE incentives which is expected to increase demand with associated security concerns on the technology's supply chain [75]. It is pertinent to note that in addition to the perceived availability challenge, government incentives are not sustainable indefinitely.

Active recycling of solar PV systems is suggested as a potential solution to addressing the material availability challenge. Specifically, German engineers appear to have made significant progress in this area with an energy-efficient pyrolysis method. This technique has allowed for the extraction of various valuable materials from SE systems, with a promising efficiency rate of up to 95% [76]. Prior to pyrolysis process, pre-treatment of waste can be challenging, which involves crushing and sieving the waste to ensure smooth processing [77]. This additional step incurs additional costs to the overall process. In the future, it is anticipated that SE entrepreneurs will be involved in a strategic plan to improve the end-of-life cycle of PV components. The plan will entrust them to consider the operational performance as well as the product recyclability to ensure a more sustainable and environmentally conscious production process.

5.2. STEM and STEAM entrepreneurship skills

The anticipated exponential expansion of the SE market is projected to be limited by scarcity of skilled and qualified human resources. This shortage can be attributed to several factors, including a misalignment between the education curriculum and the industry in-demand skills cum some incongruities in the suitability of existing curricula [25]. However, it is proposed that an expansion of STEM curriculum to STEAM with adequate entrepreneurship contents will boost the production of the needed entrepreneurship in-demand skills. While acknowledging the positive impact of STEM curriculum in supplying skilled labour to the SE sector, STEAM education is poised to offer the entrepreneurship skills 21st century graduates need to thrive as entrepreneurs in the SE sector. The skills include creative expression, artistic abilities, resilience and problem-solving. It is observed that STEAM offers a balanced approach that expands the range of applications and fosters a wider range of skills beyond traditional STEM disciplines, particularly in developing engineering and mathematical competencies [78]. Inclusion of design in STEAM is gaining recognition though the precise relationship between Design and the Arts remains a topic of contention with some schools of thought arguing that Design is a distinct field that exists alongside Art, and others suggesting that it is an integral part of the Arts [79]. With [80] stating that "Entrepreneurship is when one acts upon opportunities and ideas and transform them into value for others", it is argued that increase in the contents of Entrepreneurship in the STEAM curriculum would fast-track SET penetration whilst increasing employment in the sector. This proposition supports the assertion that currently entrepreneurship is more critical than ever as the globe faces unprecedented political and scientific challenges [81].

From the European Union Entrepreneurship Competency Framework (EntreComp), entrepreneurship as a competence, is defined as the capacity to act upon opportunities and ideas to create value which can be social, cultural, or financial. EntreComp identifies the competences that make someone entrepreneurial. These can then be used to support entrepreneurial learning in different settings – including the SES. The entrepreneurial skills and attitudes can be used as a guide when designing a new activity. Reference [82] used the EntreComp framework to identify a gap in the economics engineering curriculum and recommended introducing entrepreneurship knowledge within the curriculum. Reference [83] implemented the EntreComp framework to examine the disparities in entrepreneurship competence levels across gender and educational levels among students from seven European countries and reported that relevant entrepreneurship knowledge is insufficient. They emphasized the need for safe environments that allow students to experiment with entrepreneurial behaviours. Reference [84] conducted a similar study, using the 5 E (engage, explore, explain, elaborate, and evaluate) learning cycle and the EntreComp Framework to develop entrepreneurship skills in students. They reported that the 5 E learning cycle can enhance students' creativity and entrepreneurship. Based on the findings, it is proposed that entrepreneurial skills development can be achieved through experiential learning rather than classroom learning with motivation and perseverance the driving factor of successful entrepreneurs [85]. Thus, successful entrepreneurship in the SES will hinge on core values of motivation and perseverance because entrepreneurs encounter unlimited challenges and setbacks on the path to success. Thus, implementation of EntreComp framework in the design of SES in-demand skills in advocated.

6. The need for solar energy technology training (SETechTra) module for STEM undergraduates and graduates

Accounting for 3.6% of global electricity generation and contributing significantly to decarbonisation agenda, solar energy technologies (SETs) are identified as a key driver in the transition to low-carbon green economy and climate neutrality goals [86]. The rapid growth of SEI is yet demonstrated with the statistics that at the beginning of 2022, the global SE generation has exceeded 1 TW – recoding circa 22% growth on achievements in 2020 [87]. The statistics indicates that SE has the potential to deliver the green energy required to meet the global energy demand [88] by 2050. Global PV system installation is anticipated to be between 10 TW and 70 TW [87]. To achieve this target, government agencies globally is urged to promulgate favourable policies and all stakeholders are encouraged to do more. Fig. 13 presents the installed capacity (in MW) of solar PV system in 10 European countries from 2010 to 2022. The countries are UK, Finland, Greece, Norway, Belgium, Netherlands, France, Spain, Italy and Germany. Progressive increase in installation capacity over the 13-year period across the 10 countries is observed. As of 2022, Germany takes the lead, followed by Italy and Spain in the third position. According to Ref. [89], solar PV contributed about 26% of new generation capacity in China in 2021 with Asia leading on the growth. The United States is currently the second largest in cumulative installed PV capacity, and the third largest growth is the European Union (EU) [87]. Further studies show that 84% of the SE module installed between 2017 and 2021 in the EU was imported. This statistic is more than 77% and 75% for the United States and India, respectively. In 2021, the European Commission proposed to raise the EU's renewable energy target for 2030 from 32% to 40%. The proposed target was increased to 45% in May 2022 b y the REPowerEU Plan. This would require 1236 GW of total installed renewable capacity, including 600 GW of solar PV [90]. As the demand for the Net Zero emission continues to increase due to the challenge of climate change, so does the demand for professionals with the right skills and training in the STEM fields [91]. The observed shortage in renewable energy (RE) skills gap has necessitated an urgent need for the EU to develop a joint RE training resources to tackle the shortage and the variances in the SE manufacturing sector. It has been report by Ref. [25] that to fully realise the potential of SE, there is the need to have skilled workforce trained in SE system design, installation, and maintenance. Thus, Solar Energy Technology Training (SETechTra) is designed to support this initiative. The discussion on its contribution is presented in the following subsections.

6.1. Development of robust curricula on solar energy technologies (SETs)

SETechTra module designs and develops a good curriculum that embeds SE specific skills to the STEM undergraduates. Delivered in 12 weeks, the key contents of the module include introduction to SE systems, design of SE systems, application examples and entrepreneurial skills training. The design is informed by stakeholders from different institutions and industries, including educationist and the students, across four EU countries which includes UK, Finland, Greece and Norway. The adopted strategy supports [92,93] who identified that partnerships between HEIs and employers is critical in identifying learning requirements, improving educational relevance, and facilitating access to education and learning. In addition, it is consistent with [94] who defines curriculum as the gathering of the components of a learning system to achieve a specific goal.

Table 2 provides a summary of specific knowledge and skills as well as the anticipated outcomes that learners will acquire through the SETechTra module.

In addition to the knowledge and skills presented in Table 2, good SETechTra module/curriculum should inculcate the in-demand skills chatted in Figs. 10 and 11. For the module, academic skills should be designed into topics in weeks 1, 2 and 3. The industrial skills should be designed into topics in weeks 4, 5 and 6 while the entrepreneurial skills should be designed into topics in weeks 7, 8 and 9. Weeks 10 and 11 ought to be used for professional development involving guest lectures from stakeholders as well as industry visits. For the curriculum, year one, two and three ought to deliver academic, industrial and entrepreneurial skills, respectively to the learners.

6.2. Bridging the solar energy skills gap through production of increased industry-ready STEM graduates

As the demand for skilled labour in the SEI increases rapidly owing to

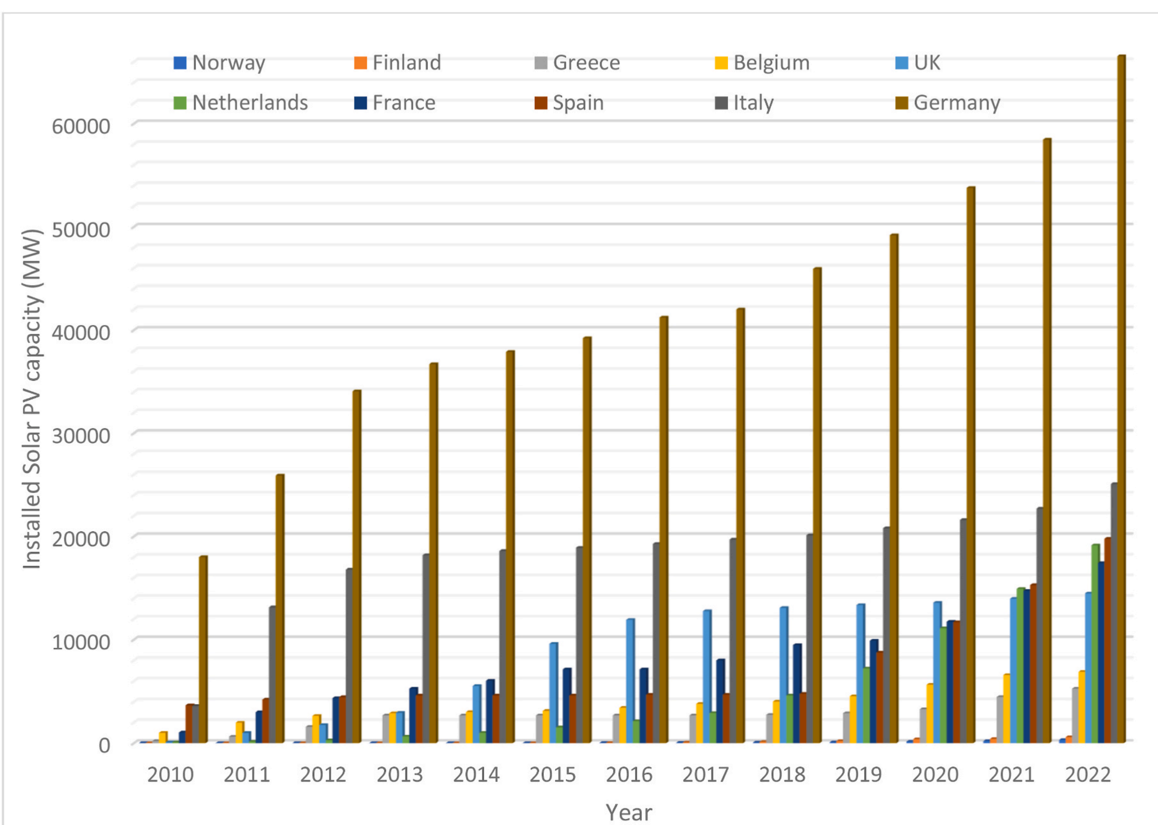

Fig. 13. Installed solar PV capacity (MW) in 10 European countries.

Table 2
Summary of specific knowledge, skills, and anticipated outcomes.

Knowledge and skills	Anticipated outcomes for the learners
Design and reliability	• Learn how to build efficient, safe, and cost-effective SE systems. • Have a better understanding of SE principles, sizing and selecting components, and creating system schematic drawing for the system.
Installation and Maintenance	• Gain knowledge about safe and efficient SE system installation techniques. This covers equipment performance monitoring and efficiency, site assessment, mounting and wiring, testing, and commissioning. • Learn how to maintain the systems so that they run smoothly and efficiently. This involves normal maintenance such as cleaning and inspection, as well as troubleshooting and repair.
Industry collaboration	• Give learners access to current industry trends and technology as well as real-world experience through the HEIs and industrial partners.
Hands-on training and practical experience	• Apply theoretical knowledge in a practical setting and gain real-world experience working with actual SE systems through laboratory exercises and fieldwork during the training programme.
Entrepreneurship and business	• Developing customer awareness, creating a business plan, and setting up a business, developing intellectual property (IP), documentation, as well as ethical issues.
Software competency	• Acquire skills in relevant solar PV engineering software including ANSYS, PVsyst, PVGIS, SolidWorks, Abaqus, RETscreen Expert, Inventor, and be able to deploy it to model real-life situations under different conditions.

numerous advantages of the technology [95], SETechTra module develops a curriculum that targets production of increasing numbers of STEM graduates with skills in SE project management, engineering, technology, maintenance and installation. More critical skills identified by Ref. [96] and which include solar thermal technology, energy storage, and grid integration are also accommodated in the curriculum. Further general competences designed into the module and which align with the work of [97] include skills in analytical and problem-solving, communication, and teamworking. A critical means of achieving these objectives is to increase the number of STEM undergraduate intake.

In a recent development, the University of Wolverhampton collaborating with partners in an Innovate UK funded project entitled "*development of innovative off-grid energy storage for sub-Saharan Africa using portable & affordable Na-ion battery system*" developed a mobile solar power energy storage system shown in Fig. 14. The system has nine foldable solar panels (9 × 450 W P solar panel) and 20 kW h energy storage capability provided by 4 × 5 kW h batteries. It is used for outreach activities at establishments including primary schools to increase SETs awareness, applications, and career opportunities. Primary schools' pupils are good targets as research has shown that early contact with them supports them to pursue a career in STEM at the critical age of 9–11 years and further in SETs in the future. As system engineering acknowledges the requirement of multi-disciplinary solutions for any systems to succeed in its purpose, the SETechTra project has considered this holistic view and included STEAM in outreach undertake by the team.

The SE skills providers are encouraged to work with business partners to develop internship programmes and job placement services for students. Such programme will provide the students the opportunity to explore the sector, make valuable connections with professionals in the sector and assess the real situation. In their research [98], reported on the challenges and opportunities for the growth of solar photovoltaic energy in Brazil. It can be demonstrated from Refs. [99,100] that low awareness about the growing demand for renewable energy sources is a major challenge. Limited availability of resources is another challenge facing SETechTra training for SE skills gap tackling. European universities, colleges and educational institutions should be boosting their stock of SE equipment and resources to provide comprehensive SETechTra curriculum. In a relevant study [101] reported on the barriers of SE uptake and the potential for mitigation solutions in Barbados. It is envisaged that a collaboration between the universities, colleges, educational institutions, and the SE industries on funding provision for equipment and resources will fast-track SETechTra curriculum deployment. The proposition is that the SE technologies skills providers develop and present a sustainable business model to the SE industries. The provision of state-of-the-art equipment in the technology is vital to SE curriculum deployment. In related investigations of [100,102], it can be deduced that limitation in the use of relevant SE technologies could adversely impact students and learner progress especially in the application of acquired skills to real-world scenarios. This challenge should be addressed to maintain engagement and achieve students and learners' progression. Political and government policy should be supporting SETechTra curriculum deployment [103].

Adoption of the SETechTra module/curriculum will provide students and learners an opportunity to deepen their knowledge and understanding of SETs and acquire the relevant SES industrial skills required to secure job in the industry. It will also enable them to develop entrepreneurial skills needed to set up SE businesses, successfully. Collaborative efforts of the skills providers including the HEIs with the stakeholders such as the SE industries, policymakers, governments, and public will be sufficient to address SETechTra curriculum deployment challenges for increased production of industry-ready STEM graduates.

7. Conclusions

This study draws from an extensive review of literature, supplemented with astute interviews and careful observations to outline critical skills needs in the solar energy technology sector (SETS) which a STEM/STEAM graduate ought to acquire to secure a lucrative employment or start-up a business in the sector. The review categorises the sector's specialist in-demand skills into three key elements of academic, industrial, and entrepreneurial skills whilst demonstrating their

(a) (b)

Fig. 14. Mobile solar power energy storage system showing (a) System folded (b) System unfolded.

complementary nature. While establishing a high degree of interaction among the three elements, the research deduces that skills in engineering, science, technology of photovoltaics, project management, marketing, and consulting are common among the elements. This research therefore proposes a strategically balanced mix of the skills as an effective means to enhance both the employability and entrepreneurial potential of STEM and STEAM graduates.

As degrees in several core engineering disciples, physics, renewable energies, sustainable technologies, business administration, marketing, management, and solar PV installation are found to embed the in-demand skills in STEM and STEAM graduates, this investigation advises that educational providers including Higher Education Institutions (HEIs) have critical role to play in providing the SETS in-demand skills – to support realisation of UN Sustainable Development Goal 7 b y 2030 and delivery of Net Zero by 2050. This research concludes that skills related to manufacturing technology of solar PV cells and modules, and deployment of solar PV modules and systems remain the two broad in-demand industrial SETS skills. To maximise STEM and STEAM graduate's entrepreneurship potential in the sector, this research advocates that skills in innovation and problem solving; leadership and problem analysis; conflict management and resolution; and customer care are indispensable.

Advancing from these conclusions, this study proposes that more Solar Energy Technology Training (SETechTra) modules for STEM and STEAM undergraduates and graduates are urgently needed in European countries' educational institutions, to embed the three key skills elements in the learners for increased employability and entrepreneurship in the SETS. It is anticipated that this review will significantly raise awareness on the skills-gap and provide HEIs with guidance on the in-demand skills in the SETS.

An ongoing research is developing the SETechTra module that incorporates the findings of this research.

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

Data will be made available on request.

Acknowledgements

The authors acknowledge the European Union for funding the project entitled "Solar Energy Technology Training (SETechTra) Module for STEM Undergraduates" which produced this article under the Erasmus + Programme of the European Union. Project detail include: €392, 000.00 total grant; 36 months duration and agreement no.: 2020-1-UK01-KA203-079236. Innovate UK is also acknowledged for supporting the development of the mobile solar power system, project No. 83383. Authors are grateful to the partners, SAMK and University of Wolverhampton, for providing some of the pictures used in this article. Contributions of Mrs Liz Fleetham, Mr Carl Williams, Dr David Pratt, and Mr Gabriel Ozique to the SETechTra project are appreciated. Mrs Fleetham leads project management, Mr Williams organised Teesside University (TU) schools and colleges outreach, Dr Pratt and Mr Ozigue supported project execution. Authors are grateful to Elsevier for the permission to reproduce Fig. 4 in this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2023.113776.

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