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Development of a Photovoltaic (PV) Solar Energy Technology Training Module for STEM Undergraduates for Solar Energy Sector Deployment

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Abstract: As the skills gap between available skills and in-demand skills in the solar energy technology sector (SETS) continues to expand due to the rapid growth of the sector, the need for Higher Education Institutions (HEIs) to design and run critical Solar Energy Technology Training (SETechTra) modules has become imperative. Informed by the findings from SETechTra project – which includes extensive literature reviews, stakeholder interviews, observations, feedback from pilot model involving circa 1500 students from schools/colleges across four European countries, this article reports on a developed strategic undergraduate (UG) 30-credit module. The module is designed to embed in-demand skills in SETS within students enrolled upon wider Science, Technology, Engineering, and Mathematics (STEM) courses. The contents of the module comprise learning and teaching activities engineered to embed key identified academic, industrial, and entrepreneurial in-demand skills in SETS in STEM UG students. Formative and summative assessments are the implemented assessment strategies used to evaluate the effectiveness and impact of the module in the pilot model. Analysis of feedback from the pilot model demonstrations indicates a significant positive impact, giving a promising indication of wider applicability to HEIs across Europe interested in fast-tracking the production of more SETS industry-ready graduates.

Keywords: *National student survey, science, technology, engineering, and mathematics (STEM), Solar energy technology sector, solar energy technology training (SETechTra), Teaching excellent framework.*

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Introduction

Solar energy technologies are increasingly gaining wider global penetration, which has driven the rapid expansion of the solar energy technology sector (SETS). A resultant surge in demand for industry-specific skilled labour has evolved in parallel.

Research shows an increasing mismatch between the demand for SETS-ready graduates due to this sector expansion and the corresponding pace at which High Education Institutions (HEIs) can produce graduates possessing the sector's

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in-demand skill set. Consequently, for sustainability of the SETS, the sector's growth ought to be re-matched with production of graduates who have the sector in-demand skills. A mismatch has been reported between the skills Europe currently possesses, and those required for the European SETS sector - with future projections having the gap further widening unless remedial action is taken. Specifically, this apparent widening is occurring as the demand for SETS sector workers is rising faster than any other renewable energy sector (RES). Currently, increasing competitiveness of the sector coupled with both the UK and other European nation's ambitious Solar Energy Technology (SET) capacity installation targets accounts for most of this rise. Figure 1 presents the global renewable energy employment for four key technologies from 2021-2022 by (Amalu et al., 2023). Figure 1 shows that employment in the solar photovoltaic (PV) energy sector is the highest among these four technologies at 4.7 million jobs. Similarly, Figure 2 depicts estimated employment opportunities in four key renewable energy sectors in Europe from 2015 to 2040 (Amalu et al., 2023). A steady overall growth in job prospects is observed, with the most significant increases in solar energy jobs being projected. These projections indicate that the SETS job is expected to reach circa 38 million jobs by 2040 and highlights the immense potential of the sector, along with the scale of coming employment opportunities within Europe and worldwide. To address the anticipated increase in employment demands over the next few decades, production of STEM graduates who possess the sector's in-demand skills needs fast-tracking, to re-align the skilled labor base with these fast growth areas.

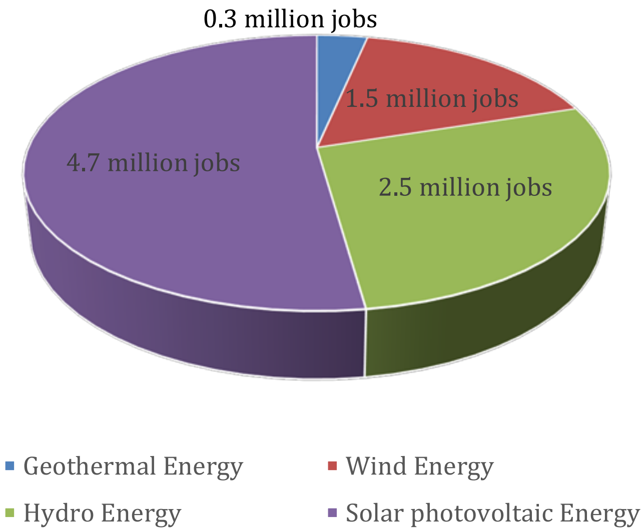

Figure 1. Global renewable energy employment for four key technologies from 2021-2022 (Amalu et al., 2023)

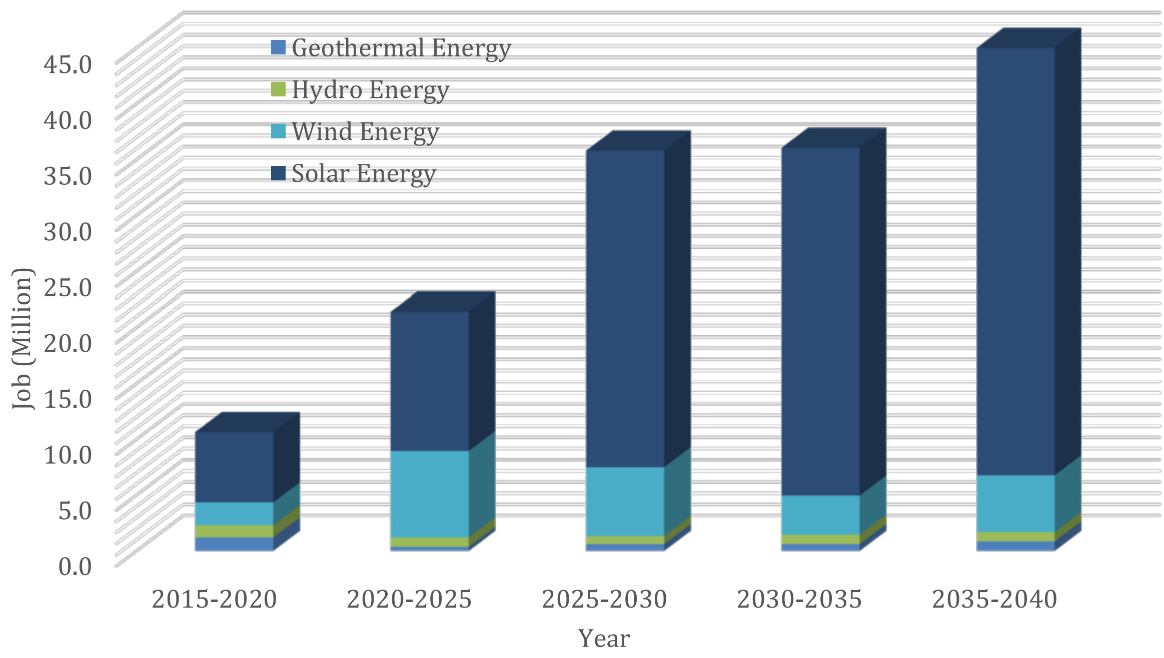

Figure 2. Estimated employment opportunities in four key renewable energy sectors in Europe from 2015 to 2040 (Amalu et al., 2023)

Addressing this issue is becoming more critical, especially considering that there are reports that this solar photovoltaic (PV) skills shortage is now limiting European Union (EU) deployment targets on solar power generation. In anticipation that the SETS skills mismatch could worsen as the demand for the skills soars, it has become more evident that the realisation of the EU's accelerated expansion of her solar power generation capacity depends critically on substantial parallel increase of the solar workforce. Findings reveal that jobs in the SETS in the EU in 2022 is circa 600,000 and is projected to rise to more than one million jobs by 2030. The prediction accommodates anticipated pressure from the related EU REPower initiative of delivering 320 GW solar capacity by 2025, with installed capacity of 600 GW by 2030. The outcome of an extensive and systematic literature review demonstrates that Germany – which has the largest EU solar market share – is projected to have shortage of circa five million SETS workers by 2030 (Amalu et al., 2023). Correspondingly, it is also reported that about 60% of German electrical contractors in SETS have job vacancies. In a similar fashion, according to the electrical contractors' association EuropaeOn, Swedish installation companies plan to hire 28,000 workers over the next five years. In the United Kingdom (UK), the number of employees in the solar photovoltaic sector in 2021 was estimated to be circa 6,400, with requirements to urgently expand to c by 2030, with a significant current and predicted shortfall of skilled labor in the sector (PwC, 2022). The National Survey Report on PV Power Applications in Finland by PV Power Systems (PVPS) estimates that there are currently about 600 full-time jobs in Finland's PV industry (Lut University, 2019).

These (and other similar) statistics have necessitated further study on the skills-gap in the UK, Finland, Greece, Norway, and also within the wider European continent to clearly identify the sector's in-demand and currently un-met skills. Moreover, discussions on the increasingly important role of engineers in achieving the UN's Sustainable Development Goals (SDGs) are gaining traction. However, there is still no sector-wide consensus within HE on the key competencies engineering students and graduates should possess to tackle the challenges of sustainability from a technical perspective (Beagon et al., 2023). Recent reviews reveal that 546 universities offer programmes focused on fossil fuels, while only 247 universities offer programmes in renewable energy. Globally, 68% of energy-related degrees emphasises fossil fuels, while just 32% focuses on renewables. Although this no doubt reflects the current usage patterns for energy generation (over 80% of global energy use was from fossil sources in 2023), fossil fuel use if declining year-on-year and it nevertheless shows a lack of foresight and preparedness for the ongoing energy transition (IEA, 2024). The figures also highlight significant gap in awareness regarding the workforce training needs in clean energy technology (Vakulchuk & Overland, 2024). Further reviews show that some programmes, such as networked learning for renewable energy transition professionals, introduce sustainability transitions theories to establish a common language across disciplines. However, they seem to primarily focus on general awareness without significant incorporation of in-depth technical skills (Huijben et al., 2022). This reflects an over emphasis on management and planning aspects, and a lack of depth regarding the specific technical skills needed in - for example - power electronics and materials science, which are needed for delivery of transition plans. Other studies (which include Delgado-Sanchez & Lillo-Bravo, 2021), have explored innovative approaches using analogies and flipped classroom techniques to improve teaching of solar energy technologies with some limitations. However, a certain theoretical framework needs to be followed in developing an appropriate curriculum that will meet the teaching needs of solar energy technology sectors, as well as meeting the needs of the diverse group of students. In recent times, the diversity in the number of students in the HEIs has impacted the method and the process of course design and development. The study by (Biggs et al., 2022) offers valuable suggestions on course design strategies in the context of a growing student population from various background. It is important that courses in higher education are designed and developed to maximize the chance that learners will experience coherence, progression and deep learning (Knight, 2002). Knight suggests that there is a need for advice on programme design and that relevant instructions and guides should be developed to target specific national markets like the solar energy.

Technical skills identification was described in detail in (Amalu et al., 2023), and related findings in (Abichandani et al., 2019; Badrakhan et al., 2022; Ciriminna et al., 2016; Jafarinejad et al., 2021) informed the outline design and development of an undergraduate (UG) SETS module for Science, Technology, Engineering, and Mathematics (STEM) students. The proposed module was designed to embed the in-demand technical skills in STEM UGs and was presented in outline form as part of the SETechTra Erasmus+ project. It was anticipated that if further developed, deployed, and managed appropriately on a wide scale, this module will contribute towards skills-gap reduction within the industry. In addition to imparting in-demand technical skills, a key target outcome of the module outline was to enhance STEM graduate employability and entrepreneurial potential.

Another outcome is to boost production of more STEM graduates embedded with the sector in-demand skills. The development of the training module discussed in this paper has been carried out within a course or programme structure, and the process is informed by relevant qualifications and quality frameworks, as well as professional body requirements. Both internal and external factors are considered in the initial planning and development stage. It is expected that the information presented in this paper would be adapted and modified to suit various continuous professional studies. There are various models that can be used in the design of courses in HEIs (Toohey, 1999) (Biggs et al., 2022). The design and development of this educational and training module followed the theoretical framework, ADDIE, developed by Florida State University in 1975 and TPACK, developed by (Mishra & Koehler, 2006). The ADDIE framework is very simple and easy to implement because it does not impose a strict linear progression through the various steps, and having stages that are clearly defined helps to facilitate implementation of effective training tools. The TPACK on the other hand focuses on technological knowledge, pedagogical knowledge, and content knowledge in the design and development of the STEM UGs training curriculum. As technology has become an increasingly important part of education and students' experience, the TPACK framework helps increase students' understanding of complex concepts and encourage collaboration among the students. Technological pedagogical knowledge (TPK) describes relationships and interactions between technological tools and specific pedagogical practices. Conversely, pedagogical content knowledge (PCK) refers to a teacher's specific experience in teaching a certain subject, including both content knowledge and knowledge of how to make that content clear and accessible to students. Furthermore, technological content knowledge (TCK) describes relationships and intersections among technologies and learning objectives. These triangulated areas constitute TPACK, which considers the relationships among all three areas and acknowledges that educators are acting within this complex space. In implementing the TPACK framework, specific technological tools (hardware, software, applications, associated information literacy practices, etc.) are best used to instruct and guide students toward a better, more robust understanding of the subject.

The aim of this article is to further develop this outline module framework, and explicitly develop and critically assess the content of a strategic solar energy technology training (SETechTra) module for STEM undergraduates. This aim was directly driven by the findings of SETechTra project. The article objectives include: (i) to Synthesis the module contents from identified SETS in-demand skills requirements; (ii) to Review and identify suitable SETS software packages and incorporate the deployment of the technologies in module contents; (iii) to Specify module critical components – including module specification, assessment strategy, intended learning outcomes and reading lists; and (v) to Discuss module implementation, evaluation, and impact. In addition, the article presents the rationale behind the developed comprehensive module, and presents some initial delivery trials and critical analysis. The objectives described above are reported further in subsequent sections on methodology, initial results/findings, discussion, recommendations, conclusion, limitations, and further work. Detailed aspects of the developed module are presented as an Appendix.

The module is designed based on the principle of constructive alignment, guided by the learning outcomes specified in The Accreditation of Higher Education Programmes, Fourth Edition (AHEP 4) by the UK Engineering Council. The module incorporates key elements such as Data Analytics, Energy Management, Design and Simulation, and Manufacturing Process Optimisation. This is to ensure that student learning is industrial relevant, meeting the standards required to prepare learners to pursue Chartered Engineer status.

Methodology

Research Design

The research design involves deployment of methods which include systematic literature review (SLR), field observation, informal interview from adversary steering board and stakeholder - each contributing unique perspectives to ensure a well-rounded development of the module (Ford et al., 2017). It aligns with the pragmatic philosophy of Dewey and others (Hoadley & Campos, 2022), making it particularly suitable for online learning, where pragmatism is essential. The research design methodology for this study is the design-based research, which aims to solve issue regarding the critical in-demand skills needs in solar energy sector through the development of training modules for implementation in some selected countries in the EU. Triangulation process, which is the method of using multiple independent sources of data to provide answers to some of the pertinent issues, has been used in this research to enhance the validity and reliability of the findings. This involves the deployment of methods which include systematic literature review (SLR), field observation, semi-structured interview from advisory steering board and stakeholder in carrying out the investigation. The advisory board and other stakeholders were helpful in the development of the curriculum. The feedback and advice by advisory board provided insight into skills alignment and allows the integration of key professional competencies into the curriculum design and development. The review of the module content by academic colleagues ensure that the module contents are aligned with other HEIs. Interview conducted ensure in-depth qualitative feedback are obtained. The information obtained from different stakeholders and through the literature help to see relevant gaps, opportunities and to compare and contrast what is being observed through a variety of opinions.

The integration of feedback from the various stakeholders in the module design was crucial in ensuring that the contents and delivery of the training is relevant, inclusive and impactful. Thus, the module content, assessment, and learning activities were updated based on the feedback and comments. The intended learning outcomes were revised to reflect industry needs and skills. Digital technologies and the use of relevant engineering software are integrated into curriculum development, and delivery methods are more flexible. Assessments were designed to be more work-based in nature, including real world application like portfolios, laboratory activities, research project, and presentations.

Sample and Data Collection

Thirty-one related articles are reviewed after passing screening tests. The literature review provides an opportunity to gather data on what scholars have researched on to date in order to understand the skill gaps. The tests ensured that bias is eliminated by employing structured techniques based on PRISMA protocol (Moher et al., 2009). The keywords of the article were searched using different search engines which include google scholar, scopus, Science Direct, and Teesside University discovery. The field observation was conducted in circa 1500 schools/colleges across four European countries which are United Kingdom, Finland, Greece, and Norway. It was conducted during the execution of a project titled Solar Energy Technology Training module for STEM undergraduate (SETechTra). Convenient sampling, a representative of the countries participating in the project, is used to select circa 1500 students and teachers from several schools/colleges across four European countries. These are the schools/colleges that participated in the outreaches, demonstrations and multiplier events of SETechTra project. In addition to the two procedures, data was gathered from adversary steering board constituted from the four partner countries in the SETechTra project. Semi-structured interview method is chosen because it is one of the best methods of gathering data for matters that are not obvious or that relate to values and attitudes (Byrne, 2004; Cohen et al., 2002). The method also gives room for flexibility during the research process, as it allows the participants to express their own opinion freely without predetermined answers from the researcher about the issue under investigation.

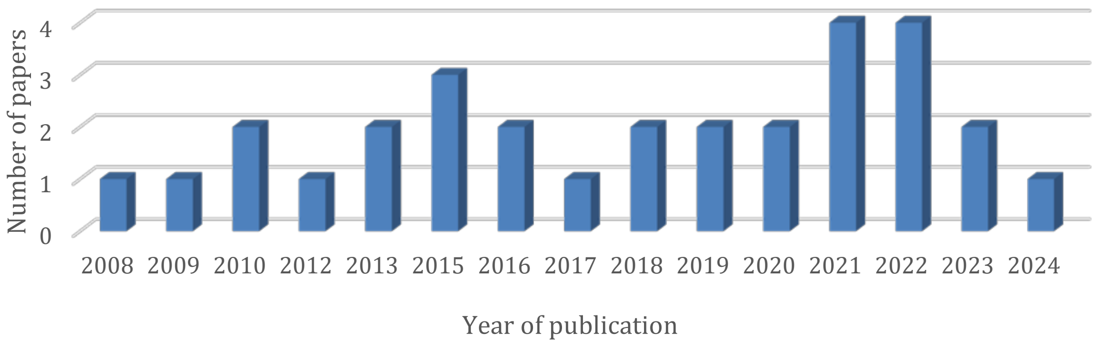

Figure 3. Plot of number of papers reviewed against the year of publication

Analyzing of Data

Thematic analysis was chosen as the approach for data analysis due to its accessibility and theoretical flexibility. This method is particularly effective for analyzing qualitative data, as it facilitates the identification and examination of patterns or themes within a dataset (Braun & Clarke, 2006). The use of thematic analysis has been shown to be effective (El Said, 2016), especially in capturing key insights gathered from informal interviews with relevant stakeholders regarding the need for the module topic. The three main steps, which are sufficient for module development, were derived by adapting the thematic analysis from (Xu & Zammit, 2020).

1. Data Familiarization: The initial step involved gathering insights from industrial stakeholders, academics, and researchers to understand the technical requirements of Solar Energy Technology Skills. This process included a literature review to assess curriculum needs, ensuring a well-balanced perspective that integrates both industry expertise and existing research.
2. Code Generation: Through discussions with various stakeholders—including academics, researchers, and industry professionals—key software tools such as “PV-F Chart” and “PV-Planner” were identified. Additionally, essential themes like “performance analysis,” “design and modeling,” and “energy management systems” were extracted from the literature. Institutional resources and facilities were also evaluated to determine their availability, helping to refine the keywords necessary for module development. This process constitutes the generation of thematic codes.
3. Theme Review: Once the keywords were established, further discussions among stakeholders were held to finalize the module topics. Although there may be contradictory perspectives on module development regarding the topics, these can be resolved by referring to AHEP 4.0 and assessing which topics can be more effectively delivered based on resource availability. The final selection was made by addressing AHEP 4.0, skill gaps, ensuring compatibility with available institutional resources, and leveraging the technical expertise of the development team.

Findings/Results

Critical software packages employed in photovoltaic module technologies

An identified constituent indispensable tool in the proposed SETechTra module is suitable software packages. The usefulness of deployment of engineering software in module delivery cannot be over emphasized. Simulation software packages have been demonstrated as very vital tool for engineering designers because it allows them to create novel systems by predicting the response of various components of the system as well as the entire system to applied load and disturbances (Gupta et al., 2010). They are used to make processes and operations more efficient - resulting in substantial time and cost savings. Moreover, simulation software packages allow many parameters to be considered simultaneously and they are particularly essential when the problems under investigation involve complex parameters (Lalwani et al., 2010; Verma et al., 2008) that need optimisation. Simulation software used in PV module technologies and in the SETS are numerous. Their deployments are found to depend on their capabilities as well as the required applications and tasks. Categorically, PV module software can be classified into two. These are design and manufacturing software, and design and application software. An attempt on holistic classification of some selected key software packages used in PV module and system technologies is presented in Figure 4. Structurally, Figure 4 classified PV module software into (i) design and manufacturing software and (ii)

design and application software. It further provided the capabilities of each group in terms of the software it contains, including the advantages of each group. Figure 5 depicts a Venn diagram which characterises the design and application software packages into four sets. These are: Design and modelling; Data analytics, reporting, fault detection & diagnostics; Performance monitoring and analysis, and reporting; and Energy & remote management system

& control. The intersection and union of these software packages in terms of deployment are clearly shown in the representation. Table 1 presents an effort on holistic assessment of these software packages. The table provides information on the software developer, origin, some specialisation and some capacities. A more detailed discussion on the software packages is presented in sections 2.1, 2.2 and 2.3. However, the attempts are proposed as a holistic guide.

Intended users are advised to obtain details and specific information of each software from the manufacturer's manual whilst adhering to the software owner’s recommendations.

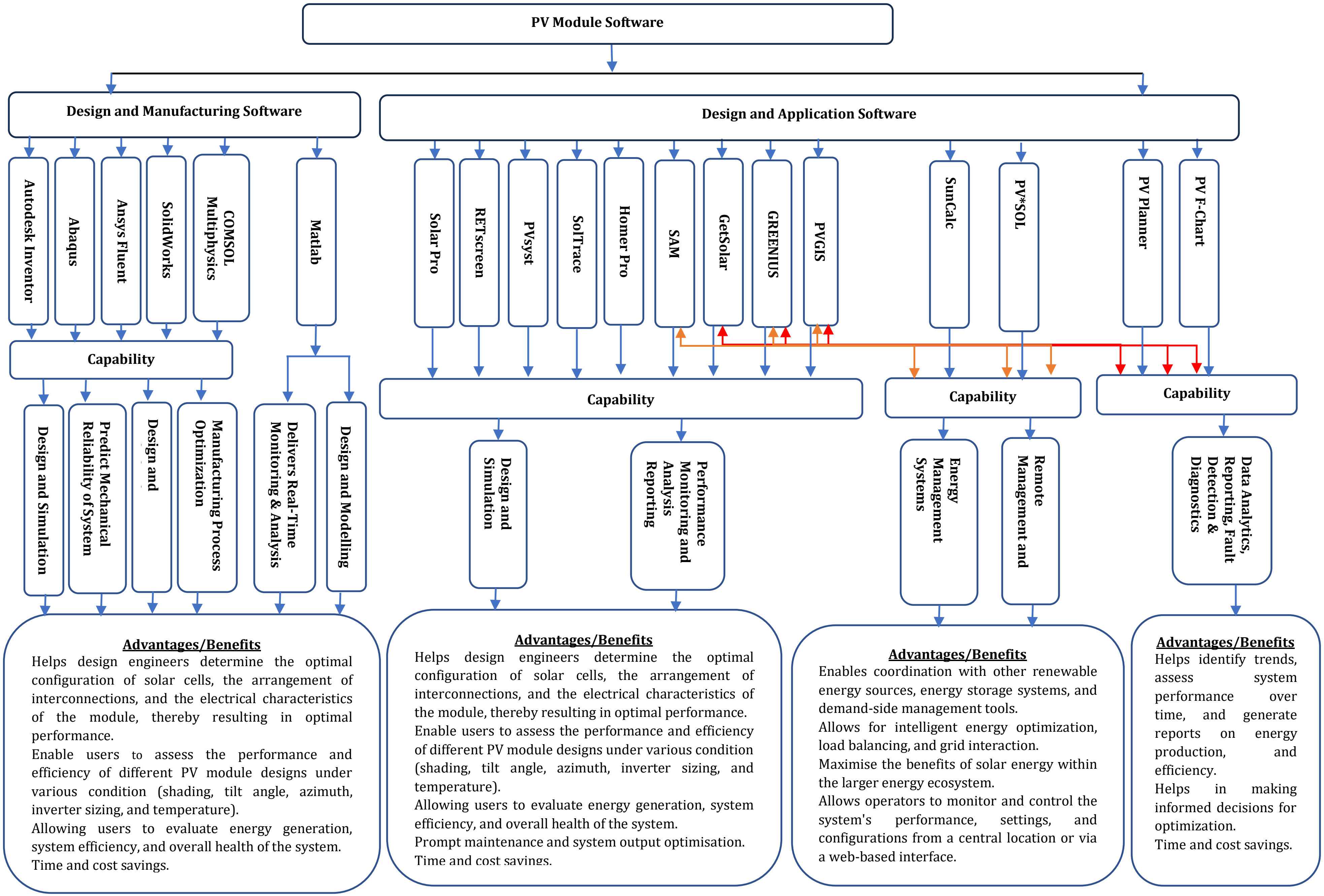

Figure 4. Classification of Software Used in PV Module and System Technologies

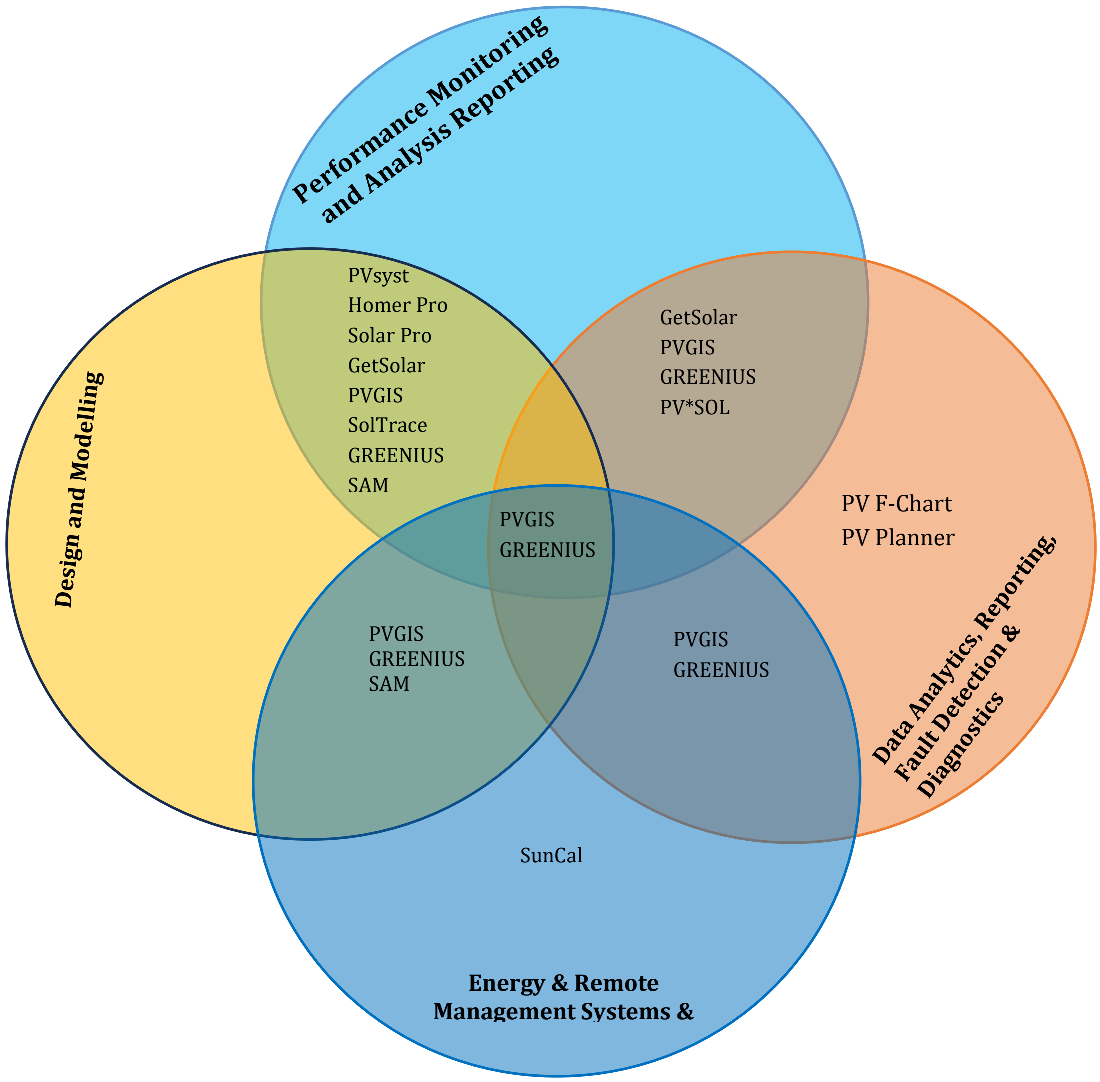

Figure 5. Venn diagram showing design and application of PV software deployment

Table 1. Holistic Assessment of Software Used in Pv System Design and Application

S/No	Name	Developer	Origin	Specialisation	Capability
1	Hybrid Optimization Model for Multiple Energy Resources (Homer Pro – Homer Energy)	National Renewable Energy Laboratory	USA	Simulation, optimization, and sensitivity analysis of PV systems.	Simulate multiple energy sources and multiple loads.
2	PV F-Chart – F-Chart software	Faculties of University of Wisconsin	USA	Targeted for academic purposes.	Uses solar radiation data to calculate PV power generation from a generic module and inverter parameters.
3	PV Planner	SolarGis	Slovakia	Cloud-based software utilising software as a service (SaaS) platform.	Estimate's location solar radiation and PV power potential.
4	PVsyst	Andre Mermoud and Michel Villoz	Switzerland	N/A	Estimates production at project planning stage.

Table 1. Continued

S/No	Name	Developer	Origin	Specialisation	Capability
5	RETscreen	National Resources	Canada	Macro enabled spreadsheet Excel-based clean energy project analysis software tool	Calculate PV power generation/other renewable energy sources based on location, do cost analysis, and determine project feasibility.
6	System Advisor Model (SAM)	Department of Energy (DoE) and National Renewable Energy Laboratory (NREL).	USA	Employed in decision making at project planning stage in renewable energy.	Estimation of energy cost for grid-connected power system based on installation and operating costs and system design parameters.
7	Solar Pro	Laplace Systems Company Limited	Japan	N/A	The software can simulate electricity generation across diverse system conditions, enabling precise data-driven system design.
8	GetSolar	ETU Software GmbH	Germany	N/A	Calculate solar yields and efficiency of a solar thermal system.
9	Photovoltaic Geographical Information System (PVGIS)	European Commission Joint Research Centr (JRC)	Italy	Solar electricity production of stand-alone or grid connected PV systems.	Calculates the monthly and yearly potential electricity generation of a photovoltaic system or plant with defined modules tilt and orientation.
10	SunCalc	N/A	N/A	Estimation of sun and moon's movement.	Computes sun and moon positions, sunlight and lunar phases for a given location and time.
11	SolTrace	National Renewable Energy Laboratory (NREL).	USA	Uses a Monte-Carlo ray trace methodology.	Modeling of optical performance of concentrating solar power (CSP) systems.
12	GREENIUS	Institute for Solar Research at German Aerospace Center (DLR)	Germany	Solar thermal power plants, PV plants, wind power parks.	Simulation of non-concentrating solar collectors for process heat supply,
13	PV*SOL	Valentin Software GmbH	Germany	Offers the most detailed configuration and shade analysis for PV systems	Calculate solar output, panel sizing and economic forecasting for your system.
14	Sunny design	N/A	Germany	Smart energy management or e-mobility tailor-made PV systems for customers.	Planning of complete energy systems. An off-grid island or hybrid system. Both for grid-connected PV system with or without a battery-storage system.

PV system design and manufacturing software: As can be deduced from Figure 4 the set of software in PV system design and manufacturing are used in processes involving mainly PV cells and modules design, manufacture and research and development. The software can be used to simulate the mechanical, thermal, and thermo-mechanical reliability of PV components, modules, and systems. This includes thermal challenges, fluid ingress into the module, thermo-mechanical degradation, cell and module architecture optimisation, module and its components stress and strain analysis as well as PV cell and module encapsulation material development. Implementation of ANSYS mechanical package in modelling thermo-mechanical deformation degradation of crystalline silicon (c-Si PV) module in operation is demonstrated in (Amalu et al., 2018), while the deployment of ANSYS Fluent in modelling thermal control of c-Si PV module using docosane phase change material (PCM) for improved performance is depicted in (Amalu & Fabunmi, 2022). Similarly, Abaqus, SolidWorks, and Matlab, are employed in (Almaktoof et al., 2021; Johansson et al., 2022; Majd & Ekere, 2020), respectively to carry out related research. Other software used in the PV system design and manufacturing process in the solar energy industry (SEI) in recent times is reported in (Lalwani et al., 2010), while Gupta et al. (Gupta et al., 2009, 2010) studied and documented several of those software packages. Software selection depends on the desirable characteristics required by businesses, particularly manufacturing and simulation features, because some software offers only basic features, while others have extensive modelling tools (Gupta et al., 2010). Law and Haider (Law & Haider, 1989) reported on the limitations of a single simulation package to all manufacturing needs. Another widely used software for PV system design and manufacturing software is the COMSOL Multiphysics. Many researchers including (Hülsmann & Weiss, 2015; Kim & Han, 2013; Koehl et al., 2012) have implemented COMSOL Multiphysics software to simulate fluid ingress into PV module and advised on the effect on fluid accumulation in the system.

PV system design and application software: Sequel to the information in Figures 4 and 5 as well as Table 1, PV system design and application software can be used to design PV systems for several applications including buildings, car parks, water pumps, communication systems, lighting systems, weather monitoring equipment, junction traffic lights, etc. In most of these applications, they are used to estimate the system's energy yield. Most of the software can create PV modules and systems, simulate the response of the system to applied environmental loads and conditions, and predict their energy yields. Most of the packages can analyse solar energy systems of all types. There are many PV system application software in the market for selection - depending on the specific task and application (Lalwani et al., 2010) - as depicted in Table 1. Research on stand-alone photovoltaic (SAPV) system assessment using PVsyst software is demonstrated in (Irwan et al., 2015) while similar application is demonstrated in (Belmahdi & El Bouardi, 2020). Implementation of PVGIS in similar research is reported in (Haffaf et al., 2021; Kale & Tarai, 2016), Homer in (Haffaf et al., 2021; Pavlović et al., 2013), RETScreen in (Owolabi et al., 2019; Pan et al., 2017). Recently, Matlab/Simulink software has been used for solar photovoltaic modelling and simulation, and this has been demonstrated to predict acceptable results (Vinod et al., 2018).

Education software aligned to SETechTra module development: Drawing from the findings of this section, several software abound which can be successfully integrated in the module delivery because several of these packages have educational and research license as well as commercial license. In consideration of SETechTra module learning outcomes, deployment of one design and manufacturing software from the set ANSYS, COMSOL, ABAQUS and one design and application software from the set PVGIS, PVsyst, RETScreen is proposed and implemented. These will provide STEM UGs the opportunity to acquire skills in both the upstream PV manufacturing field and the downstream PV deployment field.

Module Contents, Critical Components, Specification and Reading List

The module contents and critical components are presented in Table 2. The module is designed as a 30-credit module to be delivered in a 12-week in-person contact session. The table shows the weeks, the corresponding delivery components, components' delivery hours, key topics, title, and detailed content description. Structurally, the module is designed to encompass academic, industrial, and entrepreneurial needs of the learners based on uncovered SETS in-demand skills-needs and skills-gap evolution. These are captured in three key topics of (i) Introduction to solar photovoltaic technologies, (ii) Design of solar photovoltaic systems with software applications, and (iii) Entrepreneurship in solar energy technologies.

The SETecTra module is designed to support progressive development of a well-rounded learner in the SETS. Organisationally, the lectures present key theories and concepts. The seminars support the learners to develop problem solving skills pertaining to SETS in-class. Furthermore, the laboratories present the opportunity for the learners to enhance their knowledge, skills and professional practice while the assessments offer the prospect of validating the acquired knowledge and skills in the module. The key topics in weeks 1 to 3 and the assessments are designed to embed the educational needs of the learners. The week 4 topic introduces the industrial concepts and needs which are deeply explored in weeks 5 to 8. The entrepreneurial potential of the STEM students is unlocked by the learning activities of weeks 9 to 11. The SETechTra module has a total of 300 hours of learning which constitutes 82 hours in-person contact learning session plus 218 hours independent guided learning.

Assessment strategy: In HEIs, assessments provide the opportunity to evaluate how effective the learning has been and how the teaching has been received and its positive impact on the learners. Additionally, it helps to assess whether students understand the tasks and can respond appropriately, and to assess how students approach the assessment and whether their responses reflect the intended learning outcomes. Thus, the assessment strategy comprises Assessments 1 and 2. Assessment 1 is a laboratory report while assessment 2 is a portfolio. Each assessment has a 50% weighting. The detailed description of assessment brief components are:

Assessment 1 (50% of module marks): The laboratory report is on the students designing PV module of their choices. The students are expected to create a standard PV module using either Ansys, COMSOL Multiphysics or Abaqus design software packages. Carry out simulation of water ingress into the module utilising COMSOL Multiphysics or other appropriate software. In addition, they are required to carry out simulation of thermo-mechanical degradation of the module due to water ingress. Simulation output results required include plots of (i) mass, and concentration of water vapour against time accumulated in the module, (ii) degradation of the module measured by parameter which include stress, strain, deformation, and strain energy density. Based on the generated simulation results, advise on packaging, mechanical and thermo-mechanical reliability of the PV module. The report must contain at least 15 citations which are properly referenced. In addition, the report should be about 3000 words maximum excluding tables and references. However, a 10% margin is allowed. Plagiarism is checked.

Assessment 2 (50% of module marks): The portfolio is expected to cover solar PV system design and commissioning in any application of the student's choice. Applications include rooftop of household or industry, radio transmitters, parking meters, stand-alone and grid connected systems. Details of the report should include components and system sizing, component selection, mechanical and electrical installation, compliance with health and safety regulations as well as economic analysis. In addition, the use of PVGIS, PVsyst, RETScreen software package to perform the design and deployment of analytical method/testing to validate simulation results are required. Report should adopt standard academic writing style and structure. It should contain at least 15 citations that are properly referenced. The portfolio should be about 3000 words maximum excluding tables and references. However, a 10% margin is allowed. Plagiarism on the report will be checked.

The assessments were validated using various techniques to ensure they measure the intended learning outcomes. Before the assessments were released to the participants, internal and external experts in the field were invited to review the assessments to ensure the activities and tasks in the assessments cover relevant and necessary contents as well as the intended learning outcomes, and that the assessments are appropriately challenging enough. The comments and feedback provided by the experts provides opportunities to make review and revise the assessment where necessary to ensure they remain valid and effective. Rubrics that provide clear instructions and scoring matrix were provided to outline what students need to demonstrate and how they will be evaluated based on the intended learning outcomes. Furthermore, the graded assessment of the students' submitted works was moderated to ensure coherence and validity of the marking and grades awarded. The reliability of the assessment in meeting the intended learning outcomes was evaluated based on the results of the assessment from the participants from the four European countries as the assessment consistently yield similar results.

Moreover, a well-defined survey questionnaire was used to obtain comment and feedback from students on how the training and the assessments meet their expectations, including the intended learning outcomes.

Intended learning outcomes: The intended learning outcomes as derived from the UK Professional, Statutory and Regulatory Bodies (PSRBs) as well as The Accreditation of Higher Education Programmes Fourth Edition (AHEP 4) of the UK, include:

Science and Maths - C1. Apply knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Some of the knowledge will be at the forefront of the particular subject of study.

Engineering Analysis - C2. Analyse complex problems to reach substantiated conclusions using first principles of mathematics, statistics, natural science and engineering principles. C3. Select and apply appropriate computational and analytical techniques to model complex problems, recognising the limitations of the techniques employed.

Design and innovation - C5. Design solutions for complex problems that meet a combination of societal, user, business and customer needs, as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.

The engineer and society - C9. Use a risk management process to identify, evaluate and mitigate risks (the effects of uncertainty) associated with a particular project or activity.

Engineering Practice - C12: Use practical laboratory and workshop skills to investigate complex problems. C13. Select and apply appropriate materials, equipment, engineering technologies and processes, recognising their limitations. C15. Apply knowledge of engineering management principles, commercial context, project and change management, and relevant legal matters including intellectual property right.

Module reading list: The reading list advised for the SETechTra module in terms of books and journals include:

Books – The recommended books are:

- Kalogirou, S. A. (2023) - Solar energy engineering: processes and systems. Elsevier.
- Tiwari, G. N. (2023) - Advance Solar Photovoltaic Thermal Energy Technologies: Fundamentals, Principles, Design, Modelling and Applications. Springer Nature.
- Tanrioven, M. (2023) - Photovoltaic Systems Engineering for Students and Professionals: Solved Examples and Applications. CRC Press.
- Goswami, D. Y. (2022) - Principles of solar engineering. CRC press.

- Patel, M. R., & Beik, O. (2021) - Wind and solar power systems: design, analysis, and operation. CRC press.
- Abou Jieb, Y., Hossain, E., & Hossain, E. (2022) - Photovoltaic systems: fundamentals and applications. Springer.
- Duffie, J. A., Beckman, W. A., & Blair, N. (2020) - Solar engineering of thermal processes, photovoltaics and wind. John Wiley & Sons.
- Letcher, T., & Fthenakis, V. M. (Eds.). (2018) - A Comprehensive Guide to Solar Energy Systems - With Special Focus on Photovoltaic Systems. Academic Press.
- Mertens, K. (2018) - Photovoltaics: fundamentals, technology, and practice. John Wiley & Sons.
- Pearsall, N. (Ed.). (2016) - The performance of photovoltaic (PV) systems: modelling, measurement and assessment. Woodhead Publishing.
- Boxwell, M., (2017) - The Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy: How to Design and Install Photovoltaic Solar Electric Systems 2017. Greenstream Publishing Publication.
- Deutsche Gesellschaft für Sonnenenergie (DGS), (2013) - Planning and installing photovoltaic systems: a guide for installers, architects and engineers (3rd ed.). Routledge.
- G. Boyle (Ed.), (2012) - Renewable Energy: Power for a Sustainable Future (3rd ed.). Oxford University Press.
- S. Peake (Ed.), (2018) - Renewable Energy: Power for a Sustainable Future (4th ed.). Oxford University Press.

Journals - The five journals advised include:

- Energy Reports, ISSN: 2352-4847, Elsevier.
- Solar energy, ISSN: 0038-092X, Elsevier.
- Solar Energy Materials and Solar Cells, ISSN: 0927-0248, Elsevier.
- Progress in Energy; ISSN 2516-1083, IOP Publishing.
- Renewable and Sustainable Energy Reviews, ISSN: 1364-0321, Elsevier.

Table 2. 30 Credit SETechTra Module Specifications and Indicative Contents

Weeks	Delivery components (hrs)			Designation	Key topics	Title	Description
	Lecture	Seminar	Laboratory				
1	4	2		Academic skills	Introduction to solar photovoltaic technologies	Solar systems and solar energy	Solar radiation, reflections, measurements, air mass calculation solar yield calculations.
2	4	2				Solar PV technologies	Solar cell, module, system and fields. PV types.
3	4	2				Solar energy market	Technology penetration, Countries and global installation capacity, Government policies and incentives. Payback period.
4	4	2	2	Industrial skills development	Design of solar photovoltaic systems	Solar PV module and system - design (manufacture and application) manufacture, sizing, installation and maintenance.	Cell, interconnection and module structural design and reliability, Encapsulant and packaging reliability. Thermal and thermo-mechanical design and reliability, Fluid ingress and degradation qualification. Mechanical and electrical installation, Solar irradiance calculations, PV panel orientation, Global positioning, Site measurements, Insolation data, health & safety regulations.
5	4	2	2		Software applications	Application of design and manufacturing software to PV research and manufacturing.	Application of ANSYS, COMSOL, ABAQUS in design and reliability of PV module response to external loads and disturbances.
6	4	2	2				
7	4	2	2			Application of design and application software to PV system design.	Application of PVGIS, PVsyst, RETScreen Expert in design and sizing of PV system for various applications - including stand alone and grid connected systems.
8	4	2	2				
9	4	2		Entrepreneurial skills development	Entrepreneurship in Solar energy technologies	Business plan, bidding and business start-up in solar energy sector.	Business development and innovation, Economic impact of PV system, PV economic analysis, Payback period, Resilience and persistence in business. Business finance and management. Proposal and bid's writing. Conflict and risk management.
10	4	2				PV market, government policy & incentive and customer service.	Market survey including countries market shares and potentials, Implication of Government policy on Solar PV business development, PV system consulting and marketing, Mechanism of government incentive, customer relationship management, customer service.
11	4	2				Intellectual property and documentation.	Mechanism of intellectual property rights (IPR), Endogenous of IPR, Impact of IPR on economics of Solar technology business development. Implementation of procompetitive IPR standards, Report and technical writing.
12	4	2			Revision		
13			Assessment 1 (50%)			Submit a laboratory report of about 3,000 words maximum.	
14			Assessment 2 (50%)			Submit a portfolio of about 3,000 words maximum.	
Total	**48**	**24**	**10**		**82 hours contact time plus 218 hours guided independent learning**		

Comparison of the Developed Solar Energy Module With the Existing Modules

It has been highlighted that the general level of knowledge about energy and renewable energy technologies such as Solar Energy among engineering students is relatively low, with some variation in awareness across different universities in last decade (Alawin et al., 2016). In response, several curriculum initiatives have aimed to strengthen technical knowledge through advanced, hands-on learning. Ferdjallah et al. promote a practical curriculum featuring diverse laboratory experiences, including industrial control, 3D printing, energy conversion, and cyber-training labs (Ferdjallah et al., 2024). Al-Greer et al. emphasize the integration of academic rigor with industry relevance by including PV system design, fabrication, energy storage, power electronics, and safety protocols (Al-Greer et al., 2024). Meanwhile, Sung et al. adopt a multidisciplinary approach, combining solar energy engineering with geoscience education and leveraging an AI teaching assistant to enhance students' technical understanding (Sung et al., 2024).

Despite ongoing efforts, a significant gap remains that most current curricula emphasize technical competencies while overlooking the broader social, environmental, and policy contexts in which solar energy technologies function. To address this, this paper proposes integrating entrepreneurship into the curriculum—encompassing areas such as business development, PV economic analysis, market research, government policy, intellectual property rights, and key professional skills including proposal writing, risk management, and customer engagement.

The proposed module design carries important pedagogical implications, particularly in addressing persistent challenges associated with teaching technical solar energy concepts to undergraduate students. Traditional approaches—while increasingly incorporating hands-on experiences and interdisciplinary content—often struggle to engage students beyond the technical realm, limiting their ability to contextualize solar energy within real-world systems and societal needs. By embedding entrepreneurship into the curriculum, this module introduces a broader, more integrated learning framework that extends beyond engineering fundamentals. It encourages students to not only grasp the technical workings of solar technologies such as PV systems, energy storage, and power electronics but also to critically evaluate their economic viability, market readiness, and policy implications.

Discussion

The integration of advanced engineering tools is proposed for module development, focusing on manufacturing and application software packages. Manufacturing software is identified primarily for designing, producing, and conducting R&D on PV cells, modules, and systems. Contrary, application software is used for designing PV systems for end-user applications and predicting their performance in specific environments. The discussion is carried out under sub-headings which include Implementation, evaluation and impact.

Implementation: The SETechTra module was delivered in parts in an earlier version before being developed in full scale presented in this paper. The delivery was in-person contact in two universities in the European countries. These are Finland and Norway. In Finland, the delivery was in Autumn 2022. The module was delivered to 59 undergraduate students and learners in seven weeks totaling 54 hours of learning. The module activities consist of two industrial visits, six exercises and one end point assessment which was an examination. The key contents of the pilot solar training module were PV fundamental, PV systems load calculations, Solar thermal fundamental, solar thermal load calculations, PV and solar thermal systems components and selections, PV systems mounting fundamental and design as well as design and operation of trackers and large-scale systems. The contents were for both on-grid and off-grid systems. PVGIS software was implemented in the module delivery. The module was assessed by exercises and on-campus exam. The module pass mark is 40%.

Similarly, the delivery in a Norwegian university was a variant of the SETechTra module. It was delivered in-person to 4th year students of cohort size of 50 as part of an energy program. The module activities consist of 60 hours of lecture, 10 hours of laboratory and report writing, 20 hours of exercises, and 110 hours of self/independent study. The key contents of the module include electronic structure of semiconductors and nanostructured materials, carrier statistics and transport, optical processes, recombination, charge separation in Schottky barriers and pn-junction design. Other elements of the contents are loss mechanisms and efficiency in pn-junction cell, thin-film solar cell, tandem solar cell, intermediate-band solar cell and silicon-based solar cell. As correct implementation of the SETechTra module is critical to its continuous improvement and in delivering its aim and objectives, module evaluation was conducted in the two pilot deliveries.

Evaluation: In the UK, the role of module evaluation in measuring teaching excellence in the HEIs is widely accepted. Thus, Module Evaluation Survey (MES) has evolved as an effective measurement tool used to assess teaching excellence, especially at HEIs across the globe. Module evaluation has demonstrated over time to be an efficient tool because it gives the students an opportunity to provide feedback on the module to the attention of both the module leader and the university/HEIs management. With the knowledge that the feedback from MES strongly correlates with the outcome of National Student Survey (NSS), capturing feedback from students on a module before the NSS is administered is taken seriously by the university/HEI management. The NSS outcomes inform on how the universities deliver their Teaching Excellence Framework (TEF) to achieve student satisfaction. Although more recently, the government seems to be more interested in measuring students' academic experience rather than student satisfaction because satisfaction is deemed to be easily achieved by a reduction on academic rigor or delivery quality.

The knowledge of interdependence and operations among these factors are used to design Figure 6. The figure presents the relationship among module delivery, MES, NSS, TEF, student satisfaction, student academic experience and impact. Underpinned by experience spanning about two decades of delivery of several engineering modules in five countries across three continents of Europe, Asia and Africa, the key factors identified to influence quality of module delivery include delivery style, module materials, module contents, organisation and rigor. Other factors are the technologies, facilities and digital tools implemented in module delivery. Students having a clear knowledge and understanding of the in-course assessment (ICA)/homework/assignment massively contributes to quality of module delivery. In addition, students having significant knowledge of the key learning outcomes to be assessed in the Exam is also a very important factor. The importance of students understanding the assessment marking criteria cannot be over emphasised. The feedback given to the students – especially in the ICA - is not left out as it is a vital high quality module delivery factor.

Execution of MES produces either poor or good feedback from the students. In the event of poor feedback, module delivery should be reviewed to fix any identified factor(s) impacting good quality delivery. Good feedback is a positive prediction of a desirable NSS outcome. Confirmation of great NSS outcome signifies that the TEF can be adopted by the HEI because the produced graduated will be satisfied - having achieved great academic experience while at the institution. The anticipated impact on students is high with regards to continuation, progression, employment, and graduate destination. The framework presented in Figure 6 was adopted in principle in the delivery of the models of SETechTra module. The key feedback gathered from the trials are classified and presented in Figure 7. The feedback from the MES are categories into two broad categories of "positive" and "continuous improvement". There were positive comments on module materials, quality of contents, presentation mode, teaching physical models, and site/field visits. The areas of improvement identified include being more specific on the topic, cohort size and laboratory management, as well as module language.

These areas identified for continuous improvement highlight several key challenges encountered during the pilot implementation of the SETechTra module. A significant issue was managing cohort size in relation to the module's hands-on components. Larger student groups often strained the available laboratory resources, leading to limited access and occasional bottlenecks that hindered student engagement and the overall quality of practical learning experiences. Laboratory management also proved challenging, particularly when incorporating advanced digital tools and technical equipment required for solar PV experimentation. These difficulties were further exacerbated in institutions with constrained resources or limited infrastructure to support such specialised activities.

Language and clarity of delivery also emerged as important areas for improvement. Feedback indicated that some technical terms and entrepreneurial concepts were not adequately contextualized for students from non-business or non-English-speaking backgrounds. This highlights the need for clearer, more inclusive communication strategies and supplemental teaching aids. Additionally, students expressed the need for more specificity in certain topics, suggesting that some areas of the module were either too broad or insufficiently aligned with their academic background or expectations.

The feedback is implemented as practical as possible in the design of the current version of SETechTra module presented in this paper. The module is now solely on Solar PV systems. In addition, the module has three weeks dedicated on entrepreneurial skills development. This skill will support fresh graduates of the module to develop their career as Chief Executive Officer (CEO) or investor or industrialist in the SETS. Since the start-stop-continue approach of classifying feedback from MES, extensively discussed in (Hoon et al., 2015), has been established, it is recommended for implementation during delivery of SETechTra module. The recommendation arises owing to the difficulty encountered in analysing and presenting the feedback gathered during the module trials. The recommendation arises because the approach offers instructors a clear structure for comprehending and organizing feedback - where "start" designates actions to initiate, "stop" specifies action to discontinue and "continue" identifies action to sustain. An added advantage of the method is its actionable nature as it focuses on solution rather than problem identification.

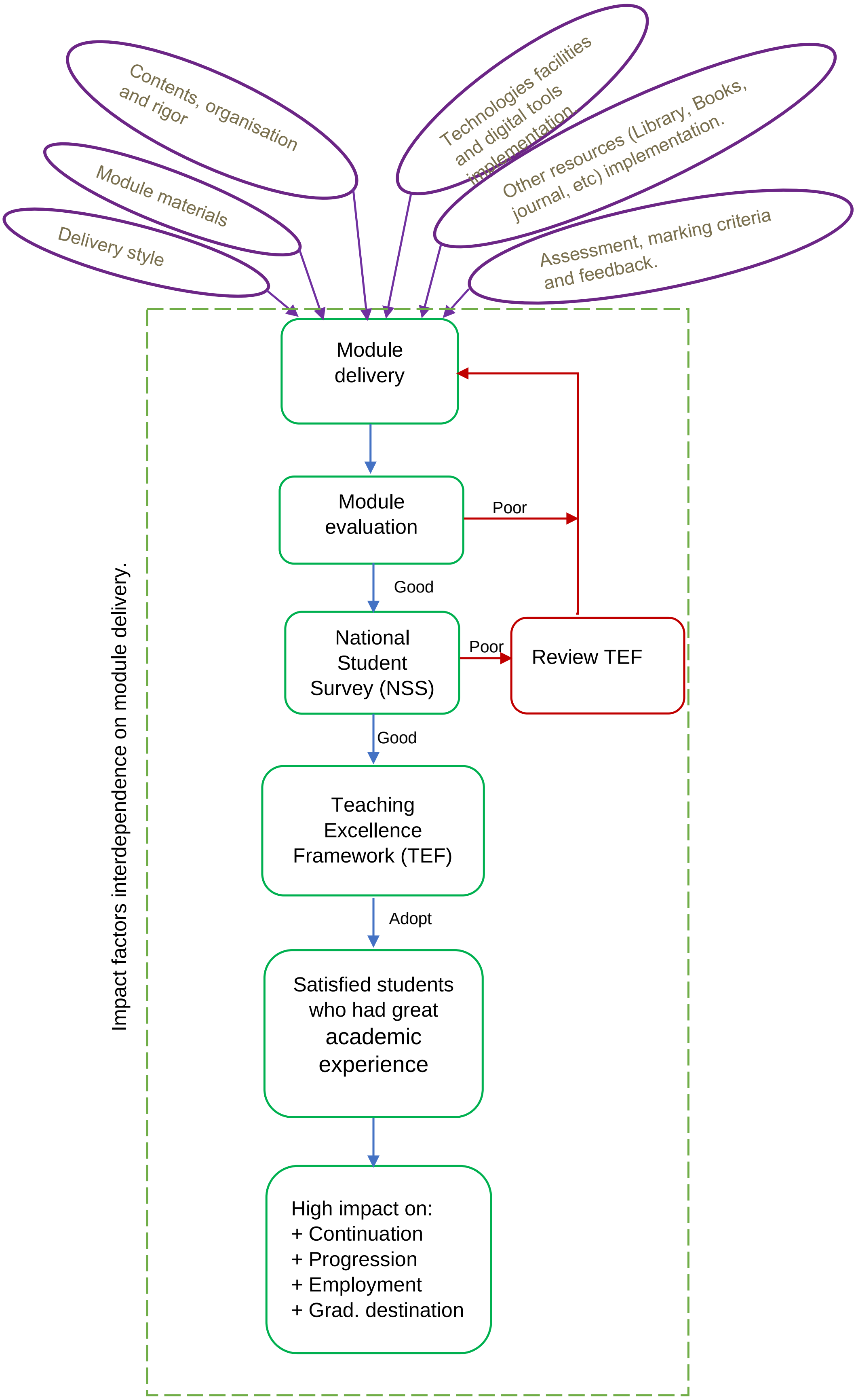

Figure 6. Relationship Among Module Delivery, Evaluation Survey, NSS, TEF, Student Satisfaction, Academic Experience and Impact

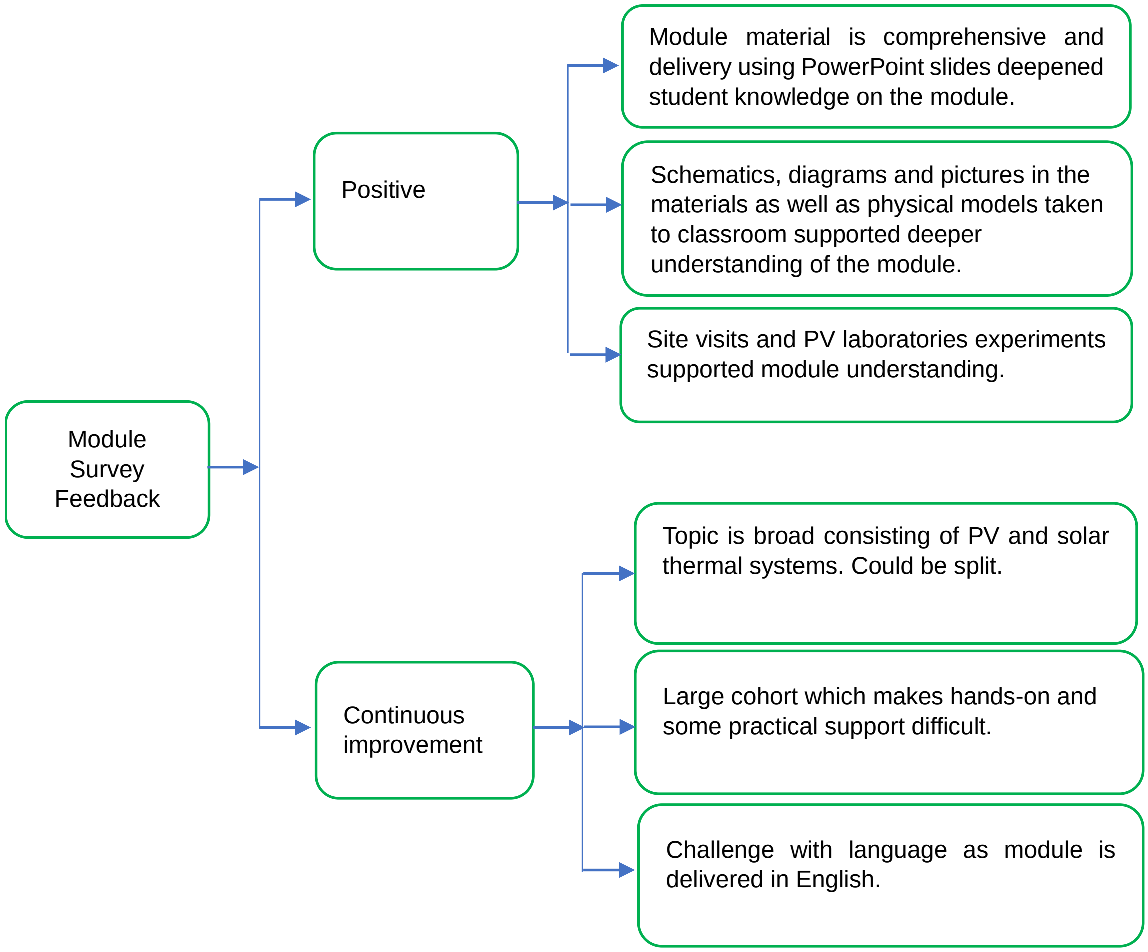

Figure 7. Feedback From the Pilot Deliveries of the Models of SETechTra Module

For instance, implementation of the start-stop-continue approach to the MES feedback discussed in Figure 7 would designate “positive feedback” as “continue”, and “continuous improvement as “start”. The design, development, and utilisation of the learning materials are to be continued because the learners find the materials comprehensive. On the other hand, “starting” the restructuring of module contents to be more specific on the subject – either PV module or PV thermal should commence. The feedback received on PV laboratory experiments and site visits is commendable. This emphasis the necessity to "continue" the strong connection with the industrial stakeholders to sustain the site visits. Although the laboratory experiments provide valuable hands-on experience, accommodating large student cohorts poses a challenge. As increasing the laboratory resources and staff may not be financially feasible, it may be strategic to "start" considering developing a virtual laboratory that can provide an equivalent engagement level to the physical laboratory. Furthermore, the language barrier suggests a growing interest in the module beyond the English-speaking communities. Therefore, it is an indication to "start" considering the development of the module in several other languages. Although the current model of the module proposed in this paper is in English Language, it is advised that the model be developed in other languages to facilitate a broader and increased penetration of SET as well as the achievement of the aim and objectives of the SETechTra module.

Impact: In the Finish delivery, the cohort achieved 86.44% pass on the module. Similarly, in the Norwegian delivery, the continuation and completion of the module was 100% at 98% pass threshold. At a combined cohort size of about 109 students with 23.73% of the Finish cohort being Erasmus+ exchange students from Saxion University of Applied Sciences, Netherlands; Ecole des Métiers de l'Environnement, UniLaSalle, France; Université Savoie Mont Blanc, France; Haute École de Namur Liège Luxembourg, Belgium; and Hochschule Bremerhaven, Germany – the module deliveries are considered to have huge impact on the production of solar energy technology skilled graduates across key European countries. In addition, the knowledge that about 10% of learners on the pilot at Norway work in the solar energy industry and used the module for upskilling, and about 5% of the cohort advanced to PhD studies in related solar energy fields, the claim on the positive impact of the module is strengthened.

To evaluate student learning performance in the context of PV module design and integration, two distinct assessments have been designed. Each assessment targets specific aspects of the students' knowledge and practical skills, providing a comprehensive evaluation of their competencies. Assessment 1 is designed to gauge the students' capability in designing a PV module. It emphasizes critical factors such as packaging, mechanical reliability, and thermo-mechanical reliability. This assessment not only tests the theoretical understanding of the students but also their ability to apply this knowledge in a practical context, considering the complexities of designing a reliable PV module. Assessment 2, on the other hand, shifts the focus to the integration of the PV module into the overall electrical system. This assessment places a significant emphasis on commissioning issues, which are pivotal for the successful deployment and operation of PV systems in real-world environments.

The combination of these assessments provides a thorough evaluation of students in both the theoretical design and practical installation of PV modules. However, assigning these tasks as individual projects may lead to over-assessment, placing a considerable burden on students and potentially impacting their overall learning experience. Arguably, learning is the students' own responsibility (Hmelo-Silver, 2004), and they should meet the demands of the learning content. However, STEM subjects have become increasingly unpopular (Bieliková, 2024), and adding excessive burdens does not create a positive learning experience, nor does it help to promote interest in STEM fields.

Understanding feedback from student learning experiences is crucial for curriculum improvement. A typical way to assess this is by setting several objective questions. However, these answers often only indicate the quality of the student learning experience and do not provide much help to improve it. Therefore, the "Start, Stop, Continue" system has been proposed as a feedback mechanism. This system encourages more engaged feedback from students, resulting in more abundant and constructive comments. Such feedback offers greater insight into strengths and weaknesses, promoting teacher reflection necessary for pedagogical improvement (Burden, 2016).

Conclusion

A solar energy technology training (SETechTra) module is developed for deployment in the Higher Education Institutions (HEIs) in the European countries. The module development is informed by an evolving in-demand skills shortages in the solar energy technology sector (SETS) in the region found during the execution of SETechTra Project. Identified SETS in-demand skills requirements are implemented to synthesis the contents of the module. These are based on the findings on the causes of the skills shortages and knowledge obtained on techniques to narrow the skills-gap to support rapid growth of the sector. To better align the developed module to industry practices, critical software packages widely used in the section which are identified from interview, observation and literature review are seamlessly incorporated in the contents of the module. The module is comprehensively designed to with specified critical components – including module specification, assessment strategy, intended learning outcomes and reading lists. Its implementation, evaluation, and impact are extensively demonstrated and discussed.

The developed SETechTra module is a 30-credit undergraduate module. It requires a total of 300 hours of learning, and it is planned for delivery in 82 hours of contact sessions and 218 hours of guided independent learning. The module has 12-weeks delivery plan. The competitiveness and attractiveness of the module are engineered by its design which is informed by inputs from stakeholders, extensive literature review, interviews, observations, feedback from pilot models involving students from circa 1500 schools/colleges across four European countries. With the pilot models demonstrating significant positive impacts, the adoption of the developed SETechTra module by the HEIs in the European union is projected to have many advantages. The contributions will lead to significant positive impacts on the SETS. Module deployment is anticipated to accelerate the production of industry-ready STEM graduates who possesses the SETS in-demand skills. This initiative will catalyst the upskilling and re-skilling of the SETS labour force - leading to speedy delivery of the UN Sustainable Development Goal 7 (SDG-7) by 2030 and Net-Zero by 2050.

Recommendations

The developed module is recommended for adoption by High Education Institutions across Europe. High Education Institutions interested in implementing the solar PV module may start by conducting needs assessment to determine students' demand and align it to industry trends. It is important to engage with renewable energy companies, policymakers, and research institutions that can help promote the module. To ensure successful integration, it is important to evaluate whether the course should be offered as an elective or mandatory subject within selected and relevant programs, or as part of a specialized solar energy track. Collaboration with industry experts to facilitate for instance guest lectures, internships, and research collaborations is crucial. Regarding the implementation, it is important to test the module as a pilot with a small group of students, gathering feedback for improvements, and later expanding it into a large group. It is further important to have continuous curriculum updates, engagement with solar energy companies, and student-led research projects that can further enhance the module's impact and prepare graduates for careers in the rapidly growing solar energy sector.

Implementation of a solar course module requires High Education Institutions to consider the policy framework and secure funding to ensure sustainability and impact. At the policy level, governments and educational authorities can promote the integration of solar energy education into national curricula, mandate solar courses in engineering and environmental science programs, and establish accreditation standards for specialized solar certifications. Policy instruments such as for instance grants, incentives for universities that invest in solar educational infrastructure, and government-supported scholarships for renewable energy degree programs can also support the long-term success of the module. In addition, public-private partnerships can strengthen political influence to integrate solar education into technical and vocational education institutions. Funding mechanisms for the course module can include government grants for renewable energy education, corporate sponsorship of solar energy companies, and collaborations with national and international organizations. Internships, research fellowships, and practical case studies that enrich the student's learning experience can be possible through collaboration between industry and academia. Such a collaboration can also lead to joint research projects, industry financed pilot plants, and workforce development initiatives that bridge the gap between academic training and industry needs. Having this collaboration in place will also ensure that the module stays up to date with the latest technology and policy changes, equipping students with relevant skills.

It is proposed that the adoption will help them to fast-track the production of more solar energy technology sector industry specialist-skill graduates.

Limitations

This study is limited by studies conducted by six partner organizations in four European countries. The countries are UK, Finland, Greece and Norway. The module is designed for undergraduate STEM program which feeds the workforce in solar energy sector. However, it can be implemented as a Continuous Professional Development (CPD) course for Technician/technologist/craftsmen working in solar energy sector.

Ethics Statements

The research described in this paper was cleared by each respective participant authors' University Ethics Committee.

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Conflict of Interest

The authors declare no conflict of interest.

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Amalu: Concept and design, data acquisition, data analysis / interpretation, drafting manuscript, critical revision of manuscript, securing funding, admin, technical or material support, final approval, analysis, writing, editing/reviewing, supervision. Adebayo: Concept and design, data acquisition, data analysis / interpretation, drafting manuscript, critical revision of manuscript, securing funding, statistical analysis, technical or material support, analysis, writing. Chong: Concept and design, data acquisition, data analysis / interpretation, drafting manuscript, critical revision of manuscript, securing funding, statistical analysis, technical or material support, analysis, writing. editing/reviewing. Short: Concept and design, interpretation, drafting manuscript, securing funding, admin, technical or material support, supervision. Hughes: Concept and design, interpretation, drafting manuscript, securing funding, admin, technical or material support, supervision. Tchuenbou-Magaia: Data acquisition, data analysis / interpretation, critical revision of manuscript, securing funding, admin, technical or material support, final approval, reviewing, supervision. Lähde: Concept and design, data acquisition, data analysis / interpretation, drafting manuscript, securing funding, admin, technical or material support, final approval, analysis, writing. reviewing, supervision. Gebremedhin: Data acquisition, data analysis / interpretation, drafting manuscript, critical revision of manuscript, statistical analysis, securing funding, admin, technical or material support, design, analysis, writing, supervision. Di Sabatino: Data acquisition, data analysis / interpretation, drafting manuscript, critical revision of manuscript, statistical analysis, securing funding, admin, technical or material support, design, analysis, writing. Ekere: Concept and design, securing funding, admin, technical or material support, design, supervision.

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