Chapter 20
Development and Implementation of BIPV Courseware for Higher Education and Professionals

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Abstract It is generally expected that in the future, photovoltaics will be able to contribute substantially to the mainstream power production, and that through their widespread commercialization, Building-Integrated Photovoltaics (BIPV) systems will become the backbone of the zero-energy building (ZEB) European target for 2020. An outlook on the BIPV market estimated the worldwide installed BIPV capacity during 2016 to nearly 2 GW, confirming the growing trend, increasing by 12.6% compared to 2015, when 1.78 GW were installed [1]. This paper presents the results of the Dem4BIPV project (http://www.dem4bipv.eu/), which has been designed to develop innovative master-level courseware for various European academic institutes focusing on Building-Integrated Photovoltaics (BIPV) in order to bridge the existing knowledge gaps in education of the target audiences (students and professionals in the building sector) as well as to create awareness on the subject. A project survey among BIPV stakeholders showed that lack of education is one of the barriers to BIPV deployment helping at the same time to identify teaching goals and subsequently courses addressing the needs of each target audience related to BIPV. Finally, a full 40 ECTS curriculum on BIPV was developed and is briefly presented in this paper.

Keywords Building-integrated photovoltaics · BIPV · Market · Education

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20.1 Introduction

The Building-Integrated Photovoltaics (BIPV) market has high potential for large-scale deployment of PV in buildings particularly in the urban environment. The outlook on the BIPV market estimates 4.8 GW for 2020 in Europe and 11.1 GW worldwide. However, despite the relatively rapid growth in the last years and the many technological advances in BIPV, its uptake has been rather slow. Lack of education is seen as one of the barriers for BIPV deployment [2]. In fact, there is a notable disparity between the progress made in terms of the technology and the knowledge and skills of the professionals (architects, engineers, designers, planners) who are ultimately responsible for the integration of BIPV systems.

Building-Integrated Photovoltaics (BIPV) has often proved to be the optimal method of installing renewable energy systems in urban, built-up areas where undeveloped land is both scarce and expensive. BIPV replaces the initial construction material, and thereby BIPV takes over its functions, BaPV (Building applied PV) is installed on top of the initial material, and its functions are thus limited to solar energy production only. It is generally expected that by mid-century photovoltaics it will be able to contribute substantially to the mainstream power production, and that through their widespread commercialization BIPV systems will become the backbone of the nearly zero-energy building (NZEB) European target for 2020 [3]. Despite technical promise, social barriers to widespread use have been identified: conservative culture of the building industry and integration with high-density urban design. A wide variety of BIPV systems are available in today's markets. In both new projects and renovations, BIPV is proving to be an effective building energy technology in residential, commercial, industrial, and institutional buildings and structures. In fact, there is a notable disparity between the progress made in terms of the technology and the knowledge and skills of the professionals (architects, engineers, designers, planners), who are ultimately responsible for the integration of BIPV systems. A consortium of leading European experts and universities launched the Dem4BIPV project [4] in 2015 in order to respond to the growing industry demand.

The specific objective of the Dem4BIPV project was to develop innovative educational material for higher education on the important topic of BIPV [4]. Its ultimate aim was to improve the quality and relevance of higher education to the labor market needs, since there is currently a gap in the knowledge and skills of graduate architects, engineers, planners, designers, etc. in relation to BIPV system design and installation. Moreover, outcomes of the project include the development of a Virtual Learning Environment (VLE) and the design and deployment of remote labs, which will enhance digital integration in learning.

20.2 Project Activities

The Dem4BIPV project had five main activities:

1. Analysis of the existing and future market needs in terms of BIPV system integration and education needs in this field, as well as an identification of the best practices in Europe mainly but not exclusively, which will result in the definition of the framework and the actual requirements of the course component.
2. Development of high-quality didactic content on BIPV for higher education.
3. Development of a virtual learning environment to support the practical aspects of the course (i.e., laboratory work of experimental nature).
4. Deployment of remote laboratories.
5. Pilot testing of the course and refinement.

The project's tangible and intangible outcomes include the following:

a. Development of appropriate and up-to-date educational material for BIPV.
b. The creation of a Virtual Learning Platform and Remote Labs for BIPV education and training.
c. Accreditation (in parallel but beyond the scope of the project).

20.3 Structure of the Introductory Course

The material includes four lectures of 90 min. Additional time for questions, about the lectures or the assignment, has been taken into account. Furthermore, when necessary, lecture slides contain notes with background information about what the slide represents. The standard structure of each lecture is recap of last lecture, new topics discussed, and when necessary there is time available to discuss, or answer questions on, the assignment. A short description of the four lectures is given below.

Lecture 1: Introduction to BIPV. The first lecture kicks off with a general introduction on the topic. What is BIPV? Why is it relevant? What is the relation with BAPV (*Building Applied Photovoltaics*) and what are the secondary functions of the BIPV system? Furthermore, a couple of examples (including architectural design) of BIPV applications are shown to create the first feeling with the topic. Finally, the advantages and disadvantages are discussed. The second half of the lecture explains the main steps from the sun to electricity consumption. It starts with how sunlight is being influenced by the atmosphere before it reaches the cell. Second, the photovoltaic effect is explained with all relevant subjects at cell level. Afterward, the focus zooms out from PV modules to complete PV systems. The lecture ends with a short introduction to the assignment.

Lecture 2: Influence on electrical performance. This lecture focusses on four topics that influence the electricity production. It explains the principles behind these topics and how negative influences can be avoided. The theory is supported by a case study at the end of every topic. These topics are influenced from tilt and orientation, PV cell types, temperature, and shading.

Lecture 3: BIPV versus conventional construction and environmental impact. The first part of this lecture makes the relation to conventional constructions without BIPV and how adding BIPV influences the internal climate of a building. It explains the influence on natural lighting, heat transmittance, and moisture protection. Further on the effect of passive heating is explained using the Trombe wall. The second part focusses on the environmental impacts of BIPV. The general idea of a life cycle analysis is explained and related to a case study of a BIPV system.

Lecture 4: Market development and aesthetics. The final lecture focusses on the implementation and the market development of BIPV. What are the barriers and what are opportunities to make BIPV a success? Main topics discussed in this lecture are price and market development, aesthetics, legislation, and drivers. The lecture ends with a perspective of the future.

Assignment

The assignment consists of two parts, "part A" and "part B", where Part A is more technical and Part B is included for a more economic and societal approach.

In Part A, students are asked to use the PVSites software tool [5] to develop a BIPV system (Fig. 20.1). This system will be introduced to the building envelope as renovation of an old 22-storey building. It should have a capacity of 1 MWp and an annual electricity production of at least 500 MWh without compromising the working conditions inside the building. The student is guided through the assignment in seven steps, every step allows the student to make their own decisions. The seven steps include irradiance, PV performance, design, aesthetics, balance of system, finances, and a reality check. Other aspects such as shading and temperature are also taken into account. Furthermore, real measured data of the electricity consumption of the building will be analyzed and used for the energy balance of the system.

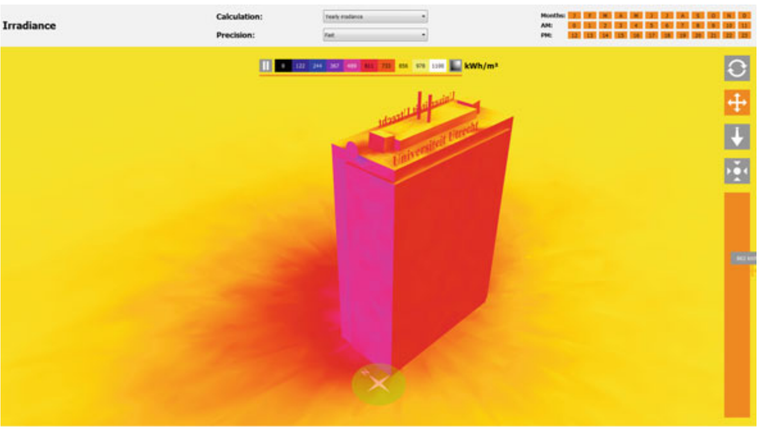

Fig. 20.1 Image of the building from PVSites software

Remote laboratories on BIPV

Additionally, in the DEM4BIPV project, the UCY, UU, and FHTW have developed each a remote BIPV laboratory with the objective to integrate it first in the introductory course on BIPV and ultimately in the more extended BIPV program outlined in Sect. 20.2. The remote labs, which are real physical experimental setups that can be accessed remotely by students for different experimental exercises, are hosted in each respective laboratory and in some cases formed part of their existing research infrastructure. The remote labs developed are as follows:

(I) *Remote laboratory for outdoor testing of BIPV modules (UCY)*: This comprises a small-scale experimental setup for testing BIPV modules in real conditions. The lab serves the purpose of measuring in real time among others BIPV electrical parameters, meteorological parameters, I-V, and thermal behavior measurements.

(II) *Multidisciplinary functional integration of PV power systems into buildings and grids (FHTW)*: The lab allows for comparative research of PV systems performance in terms of different geographic irradiation conditions, module orientation/azimuth/elevation, and different design techniques. Moreover, the lab can enable the study of the effect of aggregation of volatile energy resources (i.e., virtual power plant) and relevant methods of information modeling and communication.

(III) *Virtual laboratory using real data for simulations (UU):* The lab enables students to combine measured data from UU's outdoor PV test facility with different advanced modeling approaches for predicting PV performance of different PV module technologies on different building surfaces.

20.4 Course Evaluation by the Students

The students at UU and UCY who undertook the introductory course lectures on BIPV were requested to complete (anonymously and voluntarily) an online evaluation questionnaire on their overall experience regarding the lectures delivered. Here, we share our experience and results of students from UU and UCY who have completed the course lectures and provided feedback. For FHTW, student feedback is expected after the delivery of the respective course in February 2019. Overall, the students' response was positive in both institutions (UU, UCY).

The main results are summarized as follows:

- Most students gave a positive response to the question if they thought that the lectures covered all relevant topics related to BIPV. Suggestions for possible missing topics included other environmental impacts besides GHG emissions, how to combine BIPV with other energy producing devices, and the advantage of BIPV over BAPV;
- The majority of the students that responded felt they learned enough about the relevant topics in the introductory course.

- The most important topics were found to be barriers, end-of-life treatment, applications, multidisciplinary challenges of making BIPV mainstream, integration of BIPV in nearly zero-energy buildings, and BIPV technologies.
- On the question what BIPV topics they would like to learn more about, some suggestions included physics behind BIPV, environmental impacts and end-of-life, BIPV prospects and feasibility, market development, thermal BIPV, policy, combination with other energy productions in the building envelope, and effective integration of BIPV on a building.
- The least interesting topics were deemed to be the social barriers, colored PV, PV principles as well as legislations for NZEB and EU directives for energy efficiency in buildings.
- Most students in both institutions were positive in terms of following a complete minor course on BIPV: in UU, 25% said "yes" and 25% said "no" due to mixed reasons, e.g., there was the worry that the material will be too focused on a relatively small topic, the student background may not be technical enough for this course, etc. In UCY, a 67% of respondents said "yes" (and 33% "maybe") to this question with the justification that the BIPV may dominate the market soon, and more personal interest in the topic.
- 67% of UCY respondents and 62% of UU respondents showed preference to a BIPV assignment in the form of a case study. This was in line with the introductory lectures given which were primarily case-based. The next most popular answer was "writing a paper on a subtopic" and "presenting a paper on a subtopic."
- Most people were interested in joining a planned day to work on a BIPV assignment.

In both cases (UU and UCY), the first evaluation results of the introductory course were quite promising, and the project partners are looked carefully in order to ensure that they are taken into account in the implementation of the larger program on BIPV.

20.5 Teaching Method

For the full curriculum, various teaching methods are being used, with both teacher-centered and student-centered approaches. Every module consists of a variety of (online) courses, mainly based on MOOCs, provided by different universities. Each module has several assignments which are specifically designed for the BIPV curriculum to integrate the course material and specific reading material.

The four introductory lectures mentioned in Chap. 3 are teacher-centered in which the teacher provides information to the students based on lecture slides, and the student passively receives information and knowledge, while active participation and interaction are targeted as well. The assignment, on the other hand, is more student-centered. Clear descriptions, on what steps to make during the assignment, should be sufficient for the student to perform the assignment. However, the student is encouraged to develop its own design and must reflect on its results. Nonetheless, it is useful that a teacher is present during the tutorials. In this way, students can ask for assistance when problems occur along the road. Answers to the questions of the assignment depend on the design and/or the students' own interpretation.

20.6 40 ECTS Curriculum on BIPV

The full curriculum consists of six modules: General introduction, photovoltaics, environmental impacts, architectural aspects, energy in buildings, and future perspectives (Fig. 20.2). The curriculum covers a total of ≈1120 h of study material. A large part of the course content is based on Massive Open Online Courses (MOOCs). This way high-quality course material is created, maintained, and (possibly) graded by universities specialized in their respective fields. In the end, various topics were combined into six-module curriculum:

1. General introduction to BIPV,
2. Photovoltaics,
3. Environmental aspects,
4. Architectural aspects,
5. Energy in buildings, and
6. Future perspectives.

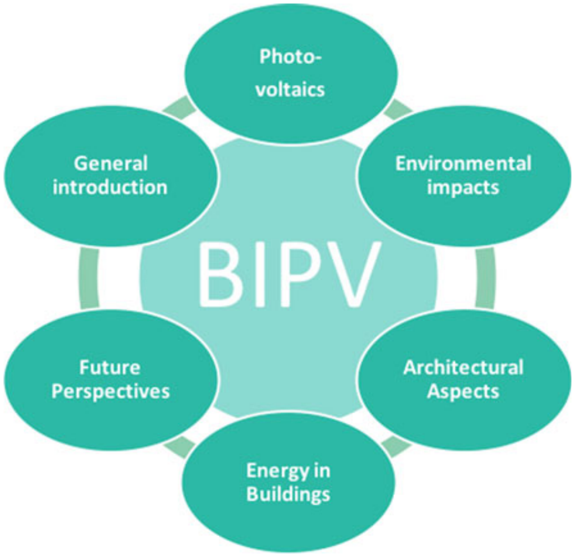

Fig. 20.2 The six modules of the BIPV curriculum

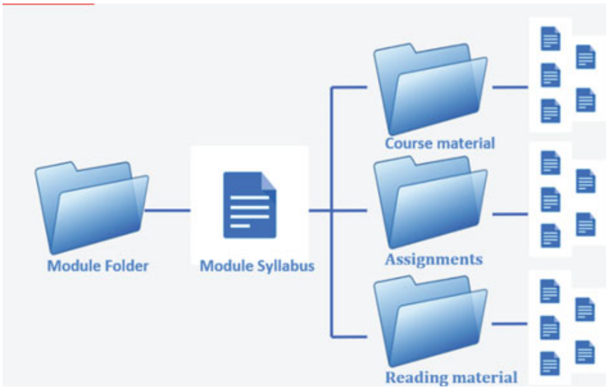

Fig. 20.3 Structure of the module folder on the website

20.7 How to Apply

From September 2018, the extended BIPV curriculum is available for use by other universities at the project website (dem4bipv.eu). The backbone of every module is the module syllabus, in which the content of each module is described (Fig. 20.3). The syllabus provides an introduction to the module, information about the teaching methods and assignments, a literature list, and a list of references and acknowledgments.

20.8 Conclusions

After a thorough investigation of the educational needs in the BIPV sector, a relevant short course was developed in detail followed by a more extended program of 40 ECTS. The Dem4BIPV introductory course has been pilot tested at the Utrecht University and at the University of Cyprus in Spring 2018. An evaluation survey was distributed after the lectures to the participants. The results of the survey will be taken into account to improve the courses in the future. From September 2018, the extended BIPV curriculum is available for use by other universities at dem4bipv.eu [3].

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