EN_1. PREFACE

At present we are experiencing explosive development in photovoltaic energy production. During the past one or two years the number of installed photovoltaic energy-generating modules has started to increase both in the developed and underdeveloped world and capacity installation projects indicate a continuation of the dynamic growth. Costs incurred by the production of solar modules decrease year on year and the reliability and efficiency of inverters are also constantly improving. Research and development (R&D) gives rise to an ever-increasing number of different types of solar panels, where, in addition to efficiency, focus must be placed also on the life-cycle of the materials used and on the reintegration of such materials into the recycling chain. From the point of view of energy management at the macro level, photovoltaic energy generation also has the advantage that a PV system makes electricity available when it is typically needed (during daytime, in the summer season when air conditioning puts transmission networks under increasing load). Possibilities for energy storage are also available (e.g. underground water storage, hydrogen storage by water-splitting). Research and development relating to electric vehicles is likely to affect the development of new and more efficient types of accumulators in the future. Although technological development promotes the spread of energy storage, political and social will play an even more significant role in this process.

The above facts may provide encouragement for the future since the surging growth rate of renewable energy exerts positive impact on our environment and provides assistance in our combating climate change, however, all this should be accompanied by a complex impact analysis of the dynamic increase in renewable energy sources. Photovoltaic energy production implies not only technical-technological prerequisites and effects but also social, economic and environmental factors and effects which are at least just as important as the former ones, consequently it is inevitable to carry out interdisciplinary research in this field. The book introduces the synopsis of the joint work performed by two research workshops of different profiles, where we address the most significant parameters relating to the social, economic, environmental and regional impacts of photovoltaic systems. The present, trilingual volume demonstrates the first findings that have emerged from complex, joint interdisciplinary research and represents a continuation of our volume entitled "Napenergia és Környezet" ("Photovoltaic Energy and Environment") (Varjú (ed.) 2014), in which we analysed the conditions for photovoltaic energy generation. In view of the initial successes and research findings giving a reason for confidence, we intend to continue working after completing our EU-funded project.

EN_2. INTRODUCTION

The European Union has recognised the enormous potential for development in the area of energy efficiency and renewable energy sources. Photovoltaic systems, as a whole, are a new technology, which generates the need to research them further. Members of the Croatian project team from the Faculty of Electrical Engineering Osijek have had the opportunity – through study visits to Barcelona, as part of the ERASMUS programme – to contact scientists working in the areas of renewable energy sources and energy electronics at the Centre for Technology Research and Development, Polytechnic University of Catalonia. They were introduced to technical achievements in various fields, whereby special emphasis was placed on photovoltaic systems. The project with the acronym REG-PHOSYS is based precisely on those kinds of experiences and research done by the project team members in the field of photovoltaic systems and energy electronics. The Institute for Regional Studies from Pécs, CERS of the Hungarian Academy of Sciences is – due to its activities in the fields of economics and environmental protection – a competent partner for the research of the social, technological and economic impacts of photovoltaic systems on the cross-border region.

The overall objective of the project is to develop an optimal photovoltaic system configuration for the climate conditions of the cross-border region. Within the scope of the project, the impact of photovoltaic systems on the electrical power supply system, economy and environment will be investigated. A common knowledge database about characteristic features significant for the application of photovoltaic systems will be developed and cross-border innovation network of research teams for development of photovoltaic systems will be established. Furthermore, the photovoltaic system will be optimized for the climate conditions of the project impact area in terms of selecting a photovoltaic module build technology. Co-operation between scientific institutions and actors of the economy on both sides of the border interested in application of photovoltaic systems will be enhanced. Location of the project in terms of research and development will be Osijek and Pécs. Location of project impact will be Eastern Croatia and Southern Hungary. The research team from the Faculty of Electrical Engineering Osijek will use innovative methods in measuring and testing photovoltaic systems, so that academic community members active in the field of PV systems, as well as PV system designers, will be able get valuable data for PV system optimisation. Also, teams will be established for innovation research, as well as for future PV system development.

An additional operational goal of the project is to set up and furnish a Laboratory for Renewable Energy Sources at the Faculty of Electrical Engineering Osijek. The direct target groups are undergraduate and graduate students of electrical engineering, who will, through laboratory and construction exercises, gain practical knowledge of photovoltaic systems. An indirect target group is members of scientific communities in the field of renewable energy sources, photovoltaic systems and PV system design in particular. Also, additional indirect target groups are businesses and potential private investors who might be motivated to invest in PV equipment development based on the PV system measurements and optimization.

The book unifies and presents project research results in all of the three research segments: technical, economic and social. An introduction to solar energy, explaining the basic concepts required for the understanding of photovoltaic system operation, is followed by the measurement results, through which the technical characteristics of photovoltaic systems with regard to the climate elements of the cross-border region are presented. An analysis of PV systems was carried out with regard to different manufacturing technologies of the photovoltaic cells, i.e. photovoltaic modules. Measurements were performed for 5 different photovoltaic modules of crystalline and thin-film structure. According to PV system structure, measurements were done on the side of the supply grid connection, i.e. AC side, and on the side of the photovoltaic modules, i.e. DC side. Based on the DC side measurements, a database was created for the purpose of evaluating the electrical power produced by the photovoltaic systems using different technologies. For the purpose of estimating the power production, a photovoltaic emulator was used.

A cost-benefit analysis shows the costs and benefits for different photovoltaic systems in the cross-border region. The cost-benefit analysis is indispensable in terms of determining the developmental priorities of photovoltaic systems, both for Croatia and Hungary. Supported by the research of the environmental impact of photovoltaic systems, as well as of their social and economic impact on the region, guidelines have been provided for selecting an optimal photovoltaic system for the cross-border region.

The book identifies potential social impacts which can be generated from several factors, such as the advance of solar energy, more particularly, solar energy-related investments, the manner in which such investments are communicated and the interaction of individual actors involved. Furthermore, the book examines the impact of the aforementioned factors on the diffusion of innovations and the influence of this process on specific groups of people as well as on their renewable/solar energy -related decisions.

When reviewing environmental impacts, we also advert to the issues of land use and carbon-dioxide emission. While making a survey of the photovoltaic life-cycle, we also take into account the waste resulting from PV panels and the recycling solutions applicable to photovoltaic modules.

Finally, we present a brief overview of where PV energy production is situated in the order of rankings relative to other renewable energy-generating solutions and also give an insight into possible advantages and disadvantages attributed to PV systems.

EN_3. INTRODUCTION TO SUN ENERGY AND PV SYSTEMS BASIC

EN_3.1. Sun radiation energy

The Sun energy is coming continuously to the Earth that is moving around it’s axes and around the Sun, therefore with daily and seasonal changes in Sun radiation on the Earth surface. Sun radiation energy E_0 coming to the other edge of Earth atmosphere depending on the Sun-Earth distance equals between 1307-1399 W/m^2 on an optimal angle surface (vertical to Sun radiation direction). An average value is called solar constant: E_{0sr}=1367.7 W/m^2. For different Sun-Earth distances we can calculate it from (Požar, 1973):

$$E_o = E_{0sr}\left(\frac{r}{R}\right)^2$$

where:

- r – average Sun-Earth distance
- R - real Sun-Earth distance (regarded constant in a day).

Due to the mild eccentricity of Earth rotation around the Sun the solar constant variants approx. ±3,4% annually, which for a certain day in the year in [W/m^2] can be calculated from (Požar, 1973):

$$E_o(n) = \varepsilon_0(n)E_{0sr} = \left(1 + 0.034\cos\frac{360^0 n}{365^0}\right)E_{0sr}$$

where:

- ε – ellipse eccentricity
- n – day in a year