PREFACE

A decade has passed since the publication of the first edition of *Comprehensive Renewable Energy*. During this time, the field of renewable energy has witnessed significant developments in all its branches and these include: photovoltaic solar energy, wind energy, solar thermal energy, fuel cells and hydrogen technology, hydropower, geothermal energy and ocean energy. The chapters from the first edition have been updated and many new chapters have been included. The first edition had 154 chapters; this edition, "*Comprehensive Renewable Energy* 2nd edition", contains 195 chapters in 9 volumes, including a new volume on environmental and social issues linked to the deployment of renewable forms of energy. Of the many books and multivolume reference works devoted to renewable energy, this compendium must rate as the most comprehensive and up-to-date compilation available.

The new edition comes at a time when the ravages of climate change are being felt in all corners of the world, with flooding, fires, melting of ice sheets and melting glaciers. As a result, the demand for renewable energy has increased over the past 10 years since the first edition of our compendium. This new set of volumes is a timeous reminder that more must be done to replace fossil fuel and it must be done fast. Our compendium is a showcase of what is being done world-wide and should give a lead to what can be done in the future.

We have assembled over 200 world class scientists, engineers, policy-makers, industrialists, environmentalists from many countries to author and co-author the chapters and produce this definitive set of the latest developments in renewable energy. The nine volumes contain colour charts, illustrations, and photographs of real projects and research results from around the world, together with many thousands of references from research journals, books and recent internet websites. The result is an authoritative overview which provides the reader with reliable background information and a citation resource for further investigation. Each chapter has been painstakingly reviewed and checked for consistent high quality.

One of the great advantages of this compendium is that each chapter has been written by a world expert in his or her chosen field and the reader is given the latest information and views of each topic. Another great advantage is that the compendium contains information on all renewable fields of endeavour and allows the reader to compare the different renewable energy technologies. Research, development and implementation of renewable energy are spread across a number of different disciplines and subject areas and having all of these in one compendium allows for a synergistic interaction between chapters which could lead to new developments and technologies. Finally, for the reader wanting to study further, there are a large number of references included in each chapter, making for easy access to further information.

Carbon dioxide levels in the atmosphere have increased since the 1880s, from 0.025% to 0.042% as measure at Mauna Loa in Hawaii. These percentages might seem small but the increase of 60% over 140 years is having a major effect on our climate. Carbon dioxide is not the major greenhouse gas; it is however, the trigger that causes a relatively small rise in temperature which in turn causes an increase in the evaporation of water from the oceans. It is this extra water vapour in the air that is the main driver of global warming. The main contributor to increased CO_2 in the atmosphere is the burning of fossil fuels. It is for this reason that renewable energy must soon replace fossil fuel and it is the major raison d'etre for our new set of 9 volumes.

The only renewable energy source we have available on Earth is radiation from the sun; there is no other. Exploitation is done directly by collecting solar energy using photovoltaic cells or concentrated solar energy and also by wind, biomass, hydropower, wave energy, all of which have been created by solar radiation.

Each volume has a dedicated editor (or editors) and it is to them that special thanks must be given for their unstinting and hard work in organizing and preparing the chapters. The names of the volume editors, together with highlights from each volume, are given below.

VOLUME 1: Photovoltaic Solar Energy

Professor Vasilis Fthenakis, Director, Center for Life Cycle Analysis, Adj. Professor, Earth and Environmental Engineering, Columbia University, New York USA. and Professor Wilfred GJHM van Sark, Copernicus Institute, Utrecht University, Utrecht, The Netherlands.

This volume, the largest in the compendium, provides a concise overview of the developments in photovoltaic (PV) solar energy and includes discussions and reports on the latest technology available. It has taken nearly 60 years for the PV industry to develop into a 100 billion dollar business, and it will probably take less than ten years to reach a trillion dollar level. This is much needed for the transition to a society based on renewable energy sources.

In order to illustrate the recent interest in photovoltaic solar energy, we note that since the publication of Volume 1 the cumulative installed capacity increased by a factor of 10¬–740 GWp by the end of 2020, while the cost decreased by a factor of about 6, which shows that the historical experience curve has continued to this day. This was due to an enormous growth in production capacity predominantly in China as well as new innovations in silicon technology, which is detailed in the updated chapter by Stephan Glunz and Ralf Preu. In the past decade, a new kid on the block showed up: thin film solar cells based on the perovskite crystal structure. A new chapter on perovskites has been added authored by Fei Zhang, Joseph Berry, and Kai Zhu, which also discusses a potential tandem cell structure that may surpass the 30% efficiency limit based on combining perovskites with

silicon technology. In the application field, a new system design has surfaced by deploying solar modules on water bodies, both inland and off-shore. With the enormous potential, the so-called floatovoltaics may be the surprise of the next decade. There are new chapters on Utility Friendly PVs, Perovskites and Floating PVs.

Finally, the increasing penetration rate of photovoltaics systems in the electricity grid may cause (local) congestion in the grid, which will be exacerbated by the increasing number of wind turbines. This leads to new options to promote self-consumption especially at the residential grid level. These are described in a new chapter by Gaëtan Masson, Francesca Tilli, and Luisa Calleri. Local grid integration will also require better spatial resolution forecasting which is demonstrated by Lennard Visser in the updated chapter on solar forecasting.

Finally, a guide to the reader is provided to facilitate retrieval of the information.

VOLUME 2: Wind Energy

Professor (Ioannis) John K. Kaldellis. Dept. of Mechanical Engineering, University of West Attica, Vice Rector of Research of UNIWA and Associate Editor of *Renewable Energy Journal*, Head of Lab of Soft Energy Applications and Environmental Protection (SEALAB), Athens, Greece.

This volume provides an overview of the state of the art in the field of wind energy technology and wind farm deployment with seventeen (17) updated chapters from the 1st edition and four (4) entirely new ones. Moreover, stemming from their classical content, four (4) chapters have remained as were in the 1st edition.

Owing to the stunning upscaling in wind turbine sizes and the continuous improvements that have taken place in wind turbine technology over the last decade, wind energy generation has noted a tremendous increase from barely 350 TWhe in 2010 to more than 1600 TWh_e in 2020, covering nowadays more than 6% of the global electricity demand. Another noteworthy feature is that offshore wind power is no more a developing energy technology but it stands out as a well-established one that is continuously increasing its share in the global energy mix. The specific subjects are underlined throughout this volume, giving special emphasis on the technological evolution of both onshore and offshore sectors.

A new chapter has been included on the reliability and maintenance of wind turbines, along with the maintenance strategies that affect the operation and maintenance planning and also their corresponding costs. Another new chapter looks at the parameters that should be examined during the financial evaluation of any wind power investment. Based on a thoroughly conceptualized analytical model, this chapter analyses cost-benefits, risk involvement, lifecycle wind energy production costs and gives an all-inclusive perspective on the financial evaluation process.

A third new chapter investigates the social acceptance of wind energy applications, focusing on the mechanisms that govern the public opinion and the reliable assessment of impacts, mitigation measures and future trends. The chapter concludes that, in order to have the desired results, early changes may need to be made in wind parks planning in order to satisfy all stakeholders involved.

Yet another new chapter describes and reviews small-scale wind turbines in terms of their components, costs, applications, opportunities for technology innovation and current and future directions for research and development.

VOLUME 3: Solar Thermal Systems: Components and Applications

Professor Soteris A. Kalogirou Professor of Mechanical Engineering, Dept of Mechanical Engineering, University of Technology, Limassol, Cyprus.

The chapters from the 1st edition have been updated and new chapters include a chapter on Urban Heat Island and Advanced Mitigating Technology, one on Solar PV and Heating and Cooling Functions and a chapter on Photovoltaic/Thermal Solar Collectors which includes innovative applications.

VOLUME 4: Fuel Cells and Hydrogen Technology

Professor Keith Scott, Electrochemical Engineering Science, Chemical Engineering, Newcastle University, NE1 7RU, United Kingdom.

Many of the chapters from the 1st edition have been updated and 12 new chapters have been included. These include chapters on future perspective on hydrogen and fuel cells; hybrid energy systems for power of sustainable buildings; phosphoric acid fuel cells; alkaline electrolysers; techno-economic analysis of hydrogen electrolysis systems; alkaline anion exchange membranes; water electrolysers – future/current perspectives in electrolysers for hydrogen production.

VOLUME 5: Biomass and Biofuel Production

Professor Tony Roskilly, Director, Sir Joseph Swan Centre for Energy Research, Stephenson Building Newcastle University, Newcastle, NE1 7RU, United Kingdom and Janie Ling-Chin Durham University, Durham, United Kingdom.

Few of the chapters from the 1st edition have been updated but most of the chapters in this volume are new topics.

The volume is divided into four sections: Global, Regional or National perspectives; Feedstocks and/or Production Processes; Use or Applications; and Life Cycle Assessment.

In the first section, there are chapters on: existing bioenergy policies worldwide covering production, power generation, biomethane, biogas, liquid biofuels, and solid biomass; opportunities for growing bioenergy crops in Europe; a review of biofuel production in a number of countries with a focus on costs, biofuel consumption, labour force, regulatory quality and financial development; and a review of biogas in Asia, investigating the socioeconomic impacts, the current socioeconomic and institutional barriers.

The second section, Feedstocks and/or Production Processes, includes chapters on: the basic characteristics of biogas and a methodology for estimating biogas production; a review on ethanol production from renewable feedstocks; a review on vegetal biomasses, including ethanol of the first and second generation, xylitol, biopolymers, biosurfactants, organic acids and other feedstocks; two reviews on hydrothermal liquefaction; a chapter on the role of solvents in enzymatic hydrolysis of cellulose and hemicellulose, sugar fermentation, and transesterification of triglycerides; a chapter on the production pathways of biogas and ethanol from biomass and algae; and a chapter on bio-electrochemical systems.

In the final section on Life Cycle Assessment, there is a chapter on LCA as a tool for assessing the environmental impacts of biofuel production; and a chapter on meta-analysis of LCA literature on woody biomass production.

VOLUME 6: Hydro Power

Professor Ånund Killingtveit, Emeritus Professor, Dept of Civil Engineering, Norwegian University of Science and Technology, Trondheim, Norway.

Hydropower is a mature technology, developed and used in over 130 years. It is by far the largest source of renewable electricity, currently supplying 4400 TWh/year, or 17% of the world electricity consumption. The electricity generation from hydropower is more than that of all other renewables combined, about three times that of wind and five times that of solar power. Hydropower is "fuelled" by water moving in the water cycle. The water cycle is powered by solar energy and will continue as long as the sun shines, making hydropower a 100% renewable energy source.

Hydropower is among the most efficient renewable electrical energy technologies, with a typical efficiency of 90% or better, "water-to-wire". Hydropower produces some of the lowest cost electricity of any generation technology. The LCOE of large-scale hydro projects at excellent sites can be as low as USD 0.02/kWh, while typical costs are in the range of USD 0.03–0.05/kWh where untapped economic resources remain.

In addition to providing energy, hydropower has technical characteristics that enable it to provide many other services to make power systems operation more reliable. Hydropower offers many very important services to the power grid, helping to maintain system stability and security of supply by providing frequency regulation, voltage support, contingency reserves, load following and black start service. It has an increasingly important role providing grid-scale energy storage and power balancing services for intermittent renewables like wind and solar. To store and save excess generation from wind and solar during periods of high supply and low demand, pumped storage hydropower (PSH) is the best option. PSH currently dominates grid storage capacity, with 96% of the world total of 176 GW installed capacity. The flexibility and storage capabilities of reservoir plants and pumped storage hydropower facilities are unmatched by any other technology.

Hydropower offers significant potential for carbon emissions reductions, since GHG emissions are generally low, usually less than 1–2% of that from coal power plants. Hydropower has the highest energy payback ratio (EPR) of all electricity generation technologies, with EPR up to 267 for run-of-river plants and 205 for storage plants.

Globally, there is still a large potential for further hydropower development, since only 28% of technical and 46% of economic potential is yet utilized. Remaining potential is largest in Asia, South America and Africa, but significant undeveloped potentials can also be found in Europa and North America. A realistic scenario is to double the annual generation from 4400 TWh (2020) to over 9000 TWh. In a recent report from the International Energy Agency (IEA) it is stated that "Reaching net-zero emissions by 2050 worldwide calls for a huge increase in hydropower ambitions".

Environmental and social impacts will need to be carefully managed. The use of new sustainability guidelines and tools for analysis should help making hydropower sustainable also in the future. Climate change can be a challenge to hydropower in some regions of the world, but also lead to increasing production in other regions. In total, global hydropower generation will probably increase. Since the future climate and hydrology will change, it is increasingly important to integrate climate change impacts in the planning process for the future hydropower system.

A few of the chapters from the 1st edition have been updated but most of the chapters in Volume 6 are new. The issues mentioned above have been expanded in the 20 chapters of this volume and there are also chapters on hydropower resources and potential, underground hydropower plants, pumped storage, sediment issues and small hydro plants. The deployment of hydropower in the Nepal, China, Norway, India, Africa and Turkey is discussed with a chapter devoted to each country and region.

VOLUME 7: Geothermal Energy

Professor Gudni Axelsson, Iceland Geo-Survey, ISOR, Geothermal Training, Reykjavik, Iceland

Volume 7 presents information on all aspects of geothermal energy, in 16 separate chapters. The first chapter reviews the setting and nature of worldwide geothermal systems ranging from extremely high-temperature systems in volcanic complexes to near-surface low-temperature heat pumps. There are three chapters on scientific methods used to identify and assess geothermal systems. There is a chapter on geothermal reservoir engineering dealing with both the theoretical and practical aspects of geothermal energy flow and extraction including mathematical modelling. The technology involved in the drilling of geothermal wells, often to a depth of 1 km, is the subject of another chapter. This is followed by three chapters dealing with different aspects of geothermal utilization and focusses on the problems of maintaining energy production, the technology of electricity generation from geothermal sources and also from shallow low-temperature thermal sources. A separate chapter deals with the statistics for geothermal energy utilization in the world in 2019, both for electricity and directly. There are two chapters dealing with chemical aspects of geothermal utilization and scaling, corrosion and material selection and a chapter on the environmental aspects of geothermal utilization including the role of geothermal utilization in sustainable development. The volume concludes with a chapter on carbon capture and storage in geothermal situations.

VOLUME 8: Ocean Energy

Professor Simon Neill, School of Ocean Science, Bangor University, Menai Bridge, Anglesea, Wales, LL59 5AR, United Kingdom.

The decade since publication of the first edition of *Comprehensive Renewable Energy* has witnessed considerable developments in the offshore renewable energy sector. However, there has been a change of emphasis from *wave energy* (which from 1970 to 2010 was seen as the leading form of ocean energy conversion) towards other forms of ocean energy technology, particularly, since it is highly predictable, *tidal energy*. During this decade, there have been extensive laboratory tests and sea trials, grid-connected demonstration devices, and small arrays of tidal stream technologies, in addition to a renewed interest in tidal *range* technology – the dominant form of operational ocean energy with around 500 MW of globally installed capacity. In the present volume, we cover the entire range of ocean energy resources and technologies, including entirely new chapters on wave energy, tidal stream energy, tidal range energy, ocean thermal energy conversion, ocean current energy, and salinity gradient energy. The volume also covers developments in ocean energy test centres, methods to measure and simulate ocean energy resources, and chapters on optimization, materials and fluid structural interaction. When extracting energy from the ocean, particularly at large scale, it is also important to consider feedbacks between energy extraction and the surrounding marine environment, and so we have also included chapters on the social and policy aspects of ocean renewable energy, and physical and biological environmental impacts.

VOLUME 9: Environmental and Social Issues

Professor Trevor M. Letcher, University of KwaZulu-Natal, Durban, South Africa.

The development and deployment of renewable energy are gaining ground rapidly and, in some cases environmental and social issues are not being considered as thoroughly as they should be. Furthermore, implementation of new technologies often does not foresee the unintended consequences linked to environmental and social issues. The extreme example is the rise of the fossil fuel industry. It is for these reasons it was felt that a special volume of *Comprehensive Renewable Energy* should be devoted to environmental and social issues, at this early stage of the renewable energy industry, so that lessons can be learnt.

This volume of 18 chapters is divided into six sections:

Introduction, Economics of Renewable Energy, Environmental Issues, Ethics, Justice and Human Migration, Local Action and Energy Aspects, and Life |Cycle Analysis. They include chapters on the difficulties in changing to a new source of energy, environmental issues relate to each of the main renewable energy sources, problems with geoengineering, justice and ethics in managing renewable energy, human migration and renewable energy, local action, engineering aspects and life.

The wide-ranging nature of the chapters gives the reader a good overall impression of the problems that lie ahead for the implementation of renewable energy.

This compendium of nine volumes has been made possible by the labours and commitment of its international authorship, the volume editors, the editorial and production staff members at Elsevier, and many others. We dedicate the product of this significant and impressive collaborative effort to our readers and trust that it will serve their needs for high-quality information on all aspects of renewable energy. Furthermore, we believe that our efforts will lead to an increased deployment of renewable energy thus replacing fossil fuel derive energy and a better world for our children and their children.

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