Silesian University of Technology

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Proceedings of the

32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems

Edited by
Wojciech Stanek, Paweł Gładysz, Sebastian Werle, Wojciech Adamczyk

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Edited by Wojciech Stanek, Paweł Gładysz, Sebastian Werle, Wojciech Adamczyk



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Preface

On behalf of the Organizing Committee, it is the greatest pleasure to welcome you to ECOS 2019 - the 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems that has been organized for the third time in Poland. This year we meet in Wroclaw - the historical capital city of Silesia and Lower Silesia, and the host of the European Capital of Culture in 2016. So far, the following editions of ECOS conference took place in Poland:

1. 1993, July 5-9, Cracow, Poland: Energy Systems and Ecology (ENSEC ´93), International Conference, Chairmen: J. Szargut, G. Tsatsaronis, Z. Kolenda, A. Ziębik.
2. 2008, June 24-28, Cracow-Gliwice, Poland: The 21st International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2008), Chairmen: Andrzej Ziębik, Zygmunt Kolenda, Wojciech Stanek.

ECOS 2019 continues the tradition of bringing together distinguished scientists, engineers and professionals as an outstanding international community of experts in the domain of energy systems. It is an honour for us to host such a distinguished community whose excellence has been, for the last three decades, at the forefront of energy systems development. All participants of the conference have the possibility to disseminate their work, to share and exchange opinions and knowledge within the sessions planned for ECOS 2019. We wish you the fruitful discussions and negotiations during the stay in Wrocław. The conference would not be possible without all the excellent papers contributed by the authors, as well as by the outstanding invited lecturers. We would like to thank all the authors for their contributions and their participation in ECOS 2019.

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ECOS Conferences and ECOS Family - brief history

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History of the ECOS Conferences is unusual in comparison to the conferences organized by different scientific societies. The meetings take place every year, since 1987, in different countries. Until now, more than 3000 papers have been presented together with excellent keynote lectures, mini-seminars and panel discussions.

ECOS is the name of international conferences dedicated to modern aspects of thermal sciences with particular attention to the general energy problems as the challenge for our civilization development. "In a world of finite natural resources and increasing energy demand by developing and poor countries, it becomes increasingly important to understand the mechanisms which degrade energy and our resources" (Professors G. Tsatsaronis and A. Valero). ECOS conferences represent a powerful tool for the systematic study in all fields of energy engineering.

Tradition of ECOS conferences goes back to the nineteen-eighties. The idea for the series ECOS Conferences originated at the ASME Winter Annual Meeting held in Miami Beach in 1985 under the leadership of Professor Richard Gaggioli.

The first international conference belonging to the ECOS group took place in Rome in 1987 as The International Symposium on Second Law Analysis of Thermal Systems under the chair of Professors R. Melli and E. Sciubba. Consecutive international meetings were organized:

- in 1989 as The international Symposium on Thermodynamic Analysis and Improvement of Energy Systems (TAIES), Beijing, chairmen – Professors C.H.Wu and R.Gaggioli,
- in 1990 as Florence World Energy Research Symposium (FLOWERS'90) organized by Professors S.S.Stecco and M.J. Moran.

The name ECOS as the acronym for ***Efficiency, Costs, Optimization and Simulation*** *of energy systems* was proposed by Professors G. Tsatsaronis and A. Valero in 1992 during conference in Zaragoza. According to Professor Christos Frangopoulos, the word "*ECOS*" means "*home*" in the Greek language and has two meanings:

- the Earth as our home that we need to protect, and
- the conference as our home for a fruitful exchange of our ideas.

ATHENS'91, Greece

The ATHENS'91 Conference (Analysis of THermal and ENergy Systems) was devoted to the analysis and improvement of the design and operation of energy systems, fundamental and applied

research in thermodynamics, heat transfer, fluid mechanics, as well as exergy and thermo-economic analysis. Professor D.A. Kouremenos was the chairman of Executive Committee with Professors R. Gaggioli and M. Moran as co-chairmen. Professor G. Tsatsaronis was the chairman of the Organising Committee with Professor C.D. Rakopoulos as co-chairman. Professor Jan Szargut was a member of Executive Committee. Keynote lecture was given by Professor E. Gyftopoulos.

ECOS'92 – Zaragoza, Spain

The first conference with the new name "ECOS" had been organized by Professors Antonio Valero (University of Zaragoza) and George Tsatsaronis (Tennessee Technological University). The ASME officially supported ECOS'92. Professor Fran Bošnjaković had been a Honorary Member of the scientific committee. Three main topics concerning energy problems were distinguished: thermodynamics and thermo-economics, process integration and advanced energy systems, energy-conversion processes and systems. Special sessions were devoted to teaching thermodynamics, thermo-economic evaluation of energy systems, IGCC power plant, cogeneration and fluidized bed combustion processes.

ENSEC'93 Cracow - Gliwice, Poland

Organized by The Institute of Thermal Technology of Silesian University of Technology and AGH – University of Science and Technology with personal support of Professor George Tsatsaronis as co-chairman. The name ENergy Systems and ECology (ENSEC) was proposed by Professor Jan Szargut, chairman of the organizing and scientific committee. The conference was devoted to modern aspects of energy engineering, including theoretical and experimental approaches to the analysis and improvement of efficiency and cost effectiveness of various energy systems and to the reduction of their environmental impact. The following keynote lectures were presented: "*The Big Bang Universe*" (Professor M. Heller), "*The Split Between Scientific and Human Values*" (Bishop, Professor J. Życiński), "*Human Values and Scientific and Technological Means*" (Professor E.P. Gyftopoulos). 112 papers from 24 countries were submitted to the conference. Professor Jan Szargut presented two lectures: "*Microphysical causes of macroscopic irreversibility*" and "*General criteria of the effectiveness of various heat production methods*".

Professors Wolfgang Fratzscher and Victor Brodianski presented papers devoted to "*Exergy calculation of chemically reacting systems*" (W. Fratzscher) , "*The prognosis for macroeconomical development and exergy*", "*Exergy in economy development*" (V. Brodianski) and "*Transit exergy in the costing definition*" (M. Sorin , V. Brodianski, A. Valero).

Professors J. Szargut, Z. Kolenda and A. Ziębik received notable distinction from the American Society of Mechanical Engineers (ASME) as chairmen of the conference.

ECOS conferences and associated sessions in the years 1994 – 2007

The regular conference ECOS under the name **FLOWERS'94** was held in Florence; chairmen– Professors E. Carnevale, G. Manfrida, F. Martelli.

Before ECOS'95 Professor E. Sciubba organized a workshop under the title *Second Law Analysis of Energy Systems; towards 21-st Century*". **ECOS'95** has been organized in Turkey, Istanbul by The Middle East Technical University and The Istanbul Technical University. The chairman was Professor Yalcin Göğüş. Professor Adrian Bejan presented the keynote lecture "*Entropy generation minimization: The method of thermodynamic optimization of finite-size systems and finite-time processes*".

ECOS'96 had been organized by Professor Gunnar Svedberg from KTH - Royal Institute of Technology, Stockholm, Sweden. Panel discussion on the transfer of knowledge of energy systems from university to industry had been included.

In the year 1997 two conferences connected with the ECOS tradition had been organized: *Thermodynamic Analysis and Improvement of Energy Systems* **(TAIES'97**) Beijing, chairman – Professor Ruixian Cai and FLOrence World Energy Research Symposium *"Clean energy for the new*

century" (**FLOWERS'97**), under the chair of Professor Giampaolo Manfrida from the University of Florence with Professors Ö. Arnas and G.Svedberg as co-chairmen. Keynote lecture was presented by Professor A.Bejan on "*Constructal Theory – from Thermodynamics and Geometric Optimization to predicting Organization in Nature".*

Professor M. Feidt from University of Nancy, was a chairman of **ECOS'98** Congress which was dedicated to Professors E.P. Gyftopoulos and P. Le Goff.

Next, the **ECOS'99** Conference was held in Tokyo under Professor Masaru Ishida from Tokyo Institute of Technology as the chairman.

ECOS'2000 had been organized by the University of Twente, Enschede, under the chair of Professor G.G. Hirs with Professor J. Szargut as the Honorary Chairman. The main part of the conference had been devoted to the problems "*From thermo-economics to sustainability*". Also, three Eurotherm Seminars on "*Process integration", "Biomass, coal and oil gasification" and "Acoustics of combustion"* were organized.

The organizers of Conference **ECOS'01** were the Istanbul Technical University and International Centre for Applied Thermodynamics together with the First International Conference on Applied Thermodynamics. Professor Aksel Öztűrk was the chairman with Professor Elias Gyftopoulos as Honorary Chairman.

Conference **ECOS'02** has been organized by Institute for Energy Engineering of Technical University Berlin. Professor George Tsatsaronis was a chairman with Professor K.F. Knoche from Technische Hochschule Aachen as Honorary Chairman. Conference was dedicated to Professor Bošnjakovic's memory. Two invited papers presented by Professors W. Fratzscher and K.F. Knoche have been devoted to Professor Bošnjaković's scientific activity.

ECOS'03 was organized by the Technical University of Denmark. The chairmen of Conference were Professors B. Quale and N. Houbak. "*Bridge to Our Energy Future*" interpreted as -"*we live in a period of transition: a transition towards deregulated energy market, towards renewable energy, towards distributed power generation and towards CO_2-neutral economy*" was the motto.

ECOS'04 was organized by Instituto Mexicano del Petroleo in Guanajuato, Mexico. The chairman of conference was Professor Ricardo Rivero.

ECOS'05 in Trondheim was organized by Norwegian University of Science and Technology with the motto "*Shaping our future energy systems*". Chairperson of the Organizing Committee was Professor Signe Kjelstrup. The program contained sessions devoted to renewable energy sources and a keynote lecture connected with CO_2 capture and storage. Also, the keynote lecture prepared by Professor Ö. Arnas was devoted to contributions to non-equilibrium thermodynamics by de Groot, Mazur and Prigogine (in memoriam), continuators Lars Onsager's achievements concerning theory of irreversible processes. Non-equilibrium thermodynamics is one of the main research field of the Norwegian University of Science and Technology. The Lars Onsager's monument is situated just there. But Lars Onsager had also contribution in the general systems theory. As fairly stressed Ludvig von Bertallanfy, who anew discovered system approach shortly before the Second World War, the mathematical form of his general systems theory is based on the mathematical notation of Onsager's theory of irreversible processes.

ECOS'06 was held in Aghia Pelagia, Crete and was organized by the National Technical University of Athens in cooperation with the ASME and the International Centre for Applied Thermodynamics (ICAT). Professor Christos Frangopoulos was the chairman with Professors George Hatsopoulos and Elias Gyftopoulos from Massachusetts Institute of Technology as Honorary Chairmen. Professor Hatsopoulos presented the keynote paper "*From entropy to enterprise using thermodynamics to build a fortune 500 company*" analyzing the practical applications of thermodynamic industrial solutions, among others cogeneration of electricity and heat (CHP) which belongs to the most effective ways of energy efficiency improvement, but its profitability depends on regulatory policy concerning domestic electro-energy system. In USA the law called PURPA (Public Utility Regulatory Policies Act of 1978) has been passed by Congress thanks to among others lobbying by Professor Hatsopoulos

company. The PURPA required electric utilities to allow their customers to the electric grid to produce electricity. Similar method has been independently proposed by Professor Jan Szargut for Polish energy systems.

ECOS'07 has been organized by Department of Mechanical Engineering of University of Padova the history of which goes back to the beginning of thirteenth century (Galileo Galilei, Erasmus of Rotterdam and Polish poet Jan Kochanowski were its students). Professor Alberto Mirandola was the chairman of the conference which was organized in cooperation with ASME and ICAT. The Department of Mechanical Engineering was established in the year 1878 by Professor Enrico Bernardi who build the first Italian car, known as "The Bernardi car". The panel session on thermodynamics education was organized under the chair of Professor M. Moran.

ECOS'2008, Cracow – Gliwice, Poland

ECOS'08, was organized again by the Institute of Thermal Technology of the Silesian University of Technology, Gliwice and the AGH University of Science and Technology of Cracow. Professors Z. Kolenda and A. Ziębik were the conference chairmen with Professor Jan Szargut as Honorary Chairman. "*Energy is too important not to use and too valuable to waste"* was a motto. It was a citation from Professor Dominick Sama's keynote lecture. Nearly two hundred papers had been sent from more than thirty countries all over the world. Besides traditional program of ECOS conferences, two mini-seminars had been organized. At first the following keynote lectures devoted to clean coal technologies were presented – Professor Jerzy Buzek, former Prime Minister of Poland, deputy chairmen of the European Parliament (member of the Industry, Research and Energy Committee and of the Climate Change Committee) – "*Climate change policy as a new threat for the EU energy*", Carl O. Bauer, Director of National Energy Technology Laboratory, Department of Energy USA – "*Addressing global energy challenges with clean coal technology*" and Professor A. Valero – "The *capture and storage of CO_2: activities of the European Technology Platform of Zero Emission Fossil Fuel Power Plants".* The second mini-seminar was devoted to fuel cells.

During conference Professor Jan Szargut received Doctor Honoris Causa degree from AGH University of Science and Technology. Professors Z. Kolenda and A. Ziębik received again the certificates from American Society of Mechanical Engineers (ASME) in recognition of their contributions to the organization of ECOS'08.

ECOS conferences in the years 2009 – 2018

ECOS'09 was held in Brazil and was organized by University of Campinas, University of Sao Paulo and Federal University of Santa Catarina. The chairperson of the conference was Professor Silvia Azucena Nebra. *"Energy and its efficient and sustainable utilization*" was the main topic.

ECOS'10 was organized by Ecole Polytechnique Federale de Lausanne, Switzerland, under Professors D.Favrat and F.Marechal as chairmen.

ECOS'11 took place in Novi Sad, Serbia, organized by the University of Niš, the University of Novi Sad, the University of Belgrad, the University of Kragujevac from Serbia and the University of Pennsylvania. Professor Gordana Stefanovic was the conference chair with Professor Noam Lior as Honorary Chairman. The motto *"International Smart Energy Networks of Cooperation for Sustainable Development*" was the main topic. Additional World Energy Panel, Special Symposium dedicated to Nicola Tesla and a Panel devoted to ethics in science and engineering were organized.

ECOS'12 was organized in Perugia by two famous Italian Universities: Rome 1 "La Sapienza" and the University of Florence. The chairmen were Professors E. Sciubba, G. Manfrida and U. Desideri.

Chinese Society of Engineering Thermophysics and Institute of Engineering Thermophysics, CAS organized **ECOS'13** in Guilin, Guangxi, China. The chairmen were Professors Jianzhong Xu and Hongguang Jin. Professor J. Szargut was a member of the Advisory Committee.

ECOS'14 has been organized by Professor Ron Zevenhoven (chairman) from Åbo Akademi University, Turku, Finland.

ECOS'15 held in Pau, France was organized by Laboratoire de Thermique, Energetique et Procedes and Ecole Nationale Superieure en Genie des Technologies Industrieles. The chairmen of the conference were Professors Jean-Pierre Bédécarrats, University of Pau with Michel Feidt, University of Lorraine, Pascal Stouffs, University of Pau, George Tsatsaronis, Technische Universität Berlin and Antonio Valero, University of Zaragoza and Professor Özer Arnas from U.S. Military Academy at West Point, as Honorary Chairman.

ECOS'16 has been organized by the Faculty of Mechanical Engineering of the University of Ljubljana, Slovenia. The conference chairs were Professors Alojz Poredoš and Andrej Kitanowski from Slovenia together with Professor Tatiana Morosuk and with Professors G. Tsatsaronis and N. Lior as Honorary Chairmen. It was 60th anniversary of the first use of the word "exergy" by Professor Zoran Rant from Slovenia.

ECOS'17 held in San Diego, California, USA was organized by Professor Asfaw Beyene from San Diego State University.

ECOS'18 has been organized by University of Minho in Guimaraes, Portugal. The conference chairs were Professors Jose Carlos Teixeira and Senhorinha Teixeira with Professors D. Favrat and S. Nebra as Honorary Chairs. Special session devoted to memory of Professor Jan Szargut was organized with 17 papers concerning his scientific activity.

ECOS Family

In the preface of the ECOS'05 proceedings the term "*ECOS family*" was used. It was quite justifiable due to common meetings within the frame of ECOS conferences. The Organizing Committee of ECOS'05 under the leadership of Professor Signe Kjelstrup presented an opinion that – "*The participants of ECOS 2005, you, are central for the realization of future energy systems that our world, our ecosystems, can sustain"*.

How important for present and future civilization are problems considered during our conferences? General opinion that "*Energy is the keystone of life and prosperity. Adequate energy supplies and a satisfactory living environment are goals of overriding importance to every individuals. There is no question that as energy is available, the quality of life improves"* [1] – is commonly accepted.

Important opinion has been presented by Professor Adrian Bejan [2] – *"Power technology will continue to evolve toward greater efficiencies and more power produced and used, not less. The pursuit of higher efficiency will not lead to less consumption. The direction has always been one-way: more power for more individuals over larger territories, and more power used by every individual."*

Also we know, that energy use is a core fundamental of modern society and almost all social activities require energy in many specific forms. Our civilization is based on expendable energy. Every effort must be made to find out not only more effective, more economical methods to use new sources of energy but also how to use renewable sources in a way that is effective and economical. Additional problems are strictly connected with the influence of energy systems on global warming and their relations to the exponentially growing world population and poverty of billions (US) of human beings.

The future of our civilization is uncertain. Now, we are facing great and important problems:

- will the world have sufficient energy to support continued economic growth?
- will that energy be secure?
- will it be sustainable?

To live in a peaceful world, we place our hopes on positive answers to the questions above. From statistical data we know that primary energy consumption is growing year by year, from 1972 more than twice with electricity generation increased more than four-times. At present, primary energy consumption growth averaged 2.2% in 2017 and carbon emissions from energy consumption increased by 1.6% and is still growing. The share of renewable is very low – 8.4% in power generation.

"*By 2050, the demand for energy could double or even triple as the global population rises and developing countries expand their economy. According to data from United Nations, it is projected that world population will increased from 7.2 billion (US) to more than 9 billion (US) in 2050 and 11.2 billion (US) in 2100. It will cause significant increase in consumption of energy and emission of greenhouse gases*" [1].

Additionally, from World Development Indicators Data, Electrical Energy Consumption is 6063 kWh/ca for European Union, 8034 for OECD countries and only 191 kWh/ca for poor countries. Also – Gross Domestic Products (GDP) amount to 38 700 USD/ca for European Union, 40 600 USD/ca for OECD countries and 848 USD/ca for poorest countries.

All above data exemplify indications and recommendations for research activities of our society in creation better world and a great civilization. Real and difficult but satisfying effort is ahead of our ECOS Family**.** We wish all of you, new and old members of ECOS Family, fruitful and interesting stay in Wrocław during 32nd International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems – ECOS 2019.

References

[1] K.J.Skipka and L.Theodore; "Energy resources-Availability, Management and Environmental Impact", CRC Press, Taylor and Francis Group, 2014.

[2] A.Bejan and J.P.Zane; "*Design In Nature",* Doubleday, New York, 2012.