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Sustainable development of energy, water and environment systems for future energy technologies and concepts

Goran Krajačić
University of Zagreb
Ivana Lučića 5, 10000 Zagreb, Croatia
Tel.: +385 91 5658884; fax: +385 1 6156940.
E-mail: Goran.Krajacic@fsb.hr

Neven Duić
University of Zagreb
Ivana Lučića 5, 10000 Zagreb, Croatia
Tel.: +385 91 5285443; fax: +385 1 6156940.
E-mail: Neven.Duic@fsb.hr

Milan Vujanović
University of Zagreb
Ivana Lučića 5, 10000 Zagreb, Croatia
E-mail: Milan.Vujanović@fsb.hr

Şiir Kılkıs
The Scientific and Technological Research Council of Turkey,
Atatürk Bulvarı No: 221, Kavaklıdere 06100, Ankara, Turkey
E-mail: siir.kilkis@tubitak.gov.tr

Marc A. Rosen
Faculty of Engineering and Applied Science
University of Ontario Institute of Technology
Oshawa, Ontario, L1H 7K4, Canada
E-mail: marc.rosen@uoit.ca

Moh'd Ahmad Al-Nimr
Jordan University of Science and Technology
Ar Ramtha, Irbid, Jordan
E-mail: malnimr@just.edu.jo

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
>
> *Our Common Future*, Report of the Brundtland Commission, 1987

> "Long live the planet. Long live Humanity. Long live the life itself. "
>
> *#ParisAgreement,* UNFCCC, COP21/CMP11, Paris, 2015

Abstract

The Conferences on Sustainable Development of Energy, Water and Environment Systems – SDEWES conferences at the beginning of the 21st century become a significant venue for researchers to meet, and initiate, discuss, share, and disseminate new ideas in various disciplines of sustainable development. In 2002, the first conference was organised in Dubrovnik, Croatia and following the tradition for odd years, the 10th SDEWES Conference again took place in Dubrovnik, Croatia from September 27th to October 2nd 2015. The total number of 1204 submitted abstracts resulted with 551 accepted manuscripts bringing 538 participants from 65 countries that participated in a number of oral and poster presentations, panels, invited lectures, and special events. Moreover, 17 special sessions were organized including 166 invited speakers.

This editorial is based primarily upon 32 papers selected from among 551 contributions presented at the 10th SDEWES Conference but it also provides a wider picture on the contributions from previous SDEWES conferences. It summarises SDEWES published articles that have addressed identified problems or provided the background for the research that is reported in the current special issue. The main topics of these papers address sustainable combustion technologies, heat exchangers, waste heat recovery, sustainable buildings, campuses and communities, renewable energy technologies and sources, as well as energy system flexibility and energy storage.

Editorial introductory to Special issue of the 10th SDEWES Conference, Dubrovnik, 2015

The Brundtland Commission clearly expressed the goal of sustainable development and necessity to understand, accept and acknowledge the needs of future generations for normal life and development. Almost 30 years after, most of the countries in the world have achieved agreement to cut the emissions of greenhouse gasses and hold the increase in the global average temperatures to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. The Paris agreement from 2015 should reduce the risks that most of the places in the world will not be hit by the global warming and climate change, while the planet, humanity and life as we know will continue to exist. Fossil fuels and industrial processes are the primary source of CO_2 emissions or further broken down to the economic activities electricity and heat production was responsible for 25%, industry for 21%, agriculture, forestry, and other land use for 24%, transportation for 14%, buildings for 6%, other energy for 10% of 2010 global greenhouse gas emissions [1].

The Conferences on Sustainable Development of Energy, Water and Environment Systems - SDEWES at the beginning of the 21st century become a significant venue for researchers to meet, and initiate, discuss, share, and disseminate new ideas in various disciplines of sustainable development. In 2002 the first conference was organised in Dubrovnik, Croatia and following the tradition for odd years, the 10th SDEWES Conference again took place in Dubrovnik, Croatia from September 27th to October 2nd 2015. The total number of 1204 submitted abstracts resulted with 551 accepted manuscripts bringing 538 participants from 65 countries that participated in a number of oral and poster presentations, panels, invited lectures, and special events. Moreover, 17 special sessions were organized including 166 invited speakers.

In 2009 at the 5th SDEWES Conference in Dubrovnik, Prof. Carvalho et al. [2] defined the outlook for a new post carbon society and the main features of future energy systems. They will be based on renewable energy sources, buildings as a positive power plants, smart grids and electric vehicles and energy storage. The papers in this special issue address key topics in the field of energy conversion and management that also sustain the series of scientific contributions towards realizing this future outlook. The readers will find papers of interest in the field of sustainable combustion technologies, various energy efficiency technologies, including heat exchangers and waste heat recovery, and energy related issues in sustainable buildings, campuses, and communities, including energy positive sites, building energy systems and polygeneration. In addition, the readers will obtain insight on leading research results from renewable energy technologies and sources, such as for solar, biomass, and biogas, as well solutions to energy system flexibility, including energy storage. This editorial is organized into these main groupings and their connections to previous SDEWES papers.

Sustainable Combustion Technologies

Until energy systems are transformed to ones that are free of fossil fuels use, it is necessary to make the transition process as smooth as possible and to improve and make the current combustion technologies more sustainable with high efficiencies and the lowest possible emissions. Thus, increases in the efficiency of the combustion process has been a primary goal of many researchers who have tried not only to improve combustion processes of fossil fuels but also improve it for many renewable and other synthetic fuels. The use of new and alternative fuels shows that combustion technologies will be important even in the low carbon energy systems. Special session at SDEWES 2015 on Sustainable Combustion Technologies was organised by Prof. Vujanović and current SDEWES special issue brings several papers from that session.

The CFD modelling of IC engines is complicated due to the highly turbulent reactive multiphase flows. It is common to use the Euler Lagrangian approach to model the high pressure liquid fuel injection, typical for compression ignition (IC) diesel engines [3]. However, such an approach suffers from severe disadvantages in modelling the processes in the near-nozzle region. To overcome these disadvantages, Euler Eulerian size of classes approach was employed by Vujanović et.al. [4]. In this SDEWES special issue, Vujanović et al. [5] present coupled simulation approach, where the Euler Eulerian multiphase approach was coupled with the Euler Lagrangian DDM approach. The authors used the code coupling interface to take advantages inherent for both approaches. They modelled the IC diesel engine working cycle for six different operating conditions and compared the emission results, as well the mean pressure traces to the experimental data. The shown coupling concept was proven as an efficient and accurate tool for modelling IC diesel engines.

The exhaust gas recirculation (EGR) can be used to lower the in-cylinder temperature and thus influence the engine raw NO_x emissions. For example, Kozarac et al. [6] had performed a numerical study of a biogas fuelled homogenous charge compression ignition (HCCI) engine and investigated the possibility of reducing the high intake temperature requirement necessary for igniting biogas by using internal EGR. The numerical analysis of four cylinder highly boosted spark-ignition engine at full load by Sjerić et al. [7] dedicated to this SDEWES special issue, focuses on introducing a high pressure EGR for control of engine limiting factors such as knock, turbine inlet temperature and cyclic variability. Authors introduced the novelty to existing numerical approaches by including modelling of cycle-to-cycle variations (CVV). The influence of EGR on the engine performance was obtained by optimising engine operating parameters. Initially, the authors tuned the cylinder and combustion models by comparison of various simulation results to the available experimental data. Afterwards, they used best coefficient set to model the turbocharged SI engine equipped with high pressure EGR loop. With addition of EGR, the authors concluded that to maintain the same load level, a fuel consumption could be increased due to the changes in turbocharger operation. They also noticed increased combustion time, lowering of the turbine inlet temperature and rise of brake specific fuel consumption (BSCF) at high engine speeds. In general, the fuel consumption increase by use of high pressure EGR and higher mechanical loads were observed.

Work carried out by Seljak et al. [8] investigated the impact of innovative fuel usage in the micro gas turbines (MGT) in terms of combustion properties and emission formation phenomena. They coupled the combustion and emission formation analyses to analyses of material degradation and degradation of component functionality. The authors investigated two fuel types with significantly different fuel properties. The main difference between the used fuels was low and high pH value. For fuels that significantly deviate from the baseline fuels, they stated that coupled approach should be used or in contrary, by using the decoupled approach for such fuels, the extent and complexity of MGT design space would be underestimated resulting in prolonged analysis time and costs. They presented a thorough list of general guidelines obtained through their methodology regarding the impact on materials, deposit formation and interrelated phenomena.

Requirements on modern power plants driven by fossil fuels are twofold. There is a need to achieve the greater efficiency of the whole facility while harmful emissions should be minimised through modifications of the combustion process or through the subsequent treatment of flue gases. In order to maintain high thermal efficiency gas turbine engines should operate at high temperatures, which are usually much higher than the allowable metal temperatures. Thus cooling of the turbine components is mandatory for the safe operation. Air film cooling is nowadays a commonly employed method for the external turbine blade cooling. Wang et al. [9] analysed the influence of the particle dispersion onto the continuous phase in film cooling application by means of numerical simulation. The prediction of two-phase flow was investigated by employing the discrete phase model (DPM), which was also used for mathematical representation of spray in Baleta et al. [10]. The results present heat transfer characteristics in the near-wall region under the influence of mist cooling and surface deposits of different heights. The local wall temperature distribution and film cooling effectiveness show that the film cooling characteristics on the downstream wall are affected by different height of surface deposits. It was also found that smaller deposits without mist injection provide a lower wall temperature and a better cooling performance. With 2% mist injection, evaporation of water droplets improves film cooling effectiveness, and higher deposits cause lateral and downstream spread of water droplets. Finally, it was concluded that mist injection can significantly enhance film cooling performance.

Tightened NO_x emission standards on industrial emissions from combustion plants cannot be met using described primary NO_x reduction techniques anymore. Also, it is difficult to implement those techniques into existing facilities. Selective non-catalytic reduction (SNCR) is a proven cost-effective secondary method of NO_x control from big stationary sources such as power plants, incinerators, boilers and cement calciners and Baleta et al. [11] performed numerical analysis of relevant physical phenomena taking place within the SNCR facility. First step was testing of all relevant models preceding the incorporated mechanism on well-established experimental case. Parametrisation of urea thermolysis model was performed on one case, yielding good agreement on all other cases. Furthermore, implemented mechanism was validated on the real industrial reactor for which experimental results can be found in the literature as well as on the case of municipal waste incinerator. Simulated results show satisfactory agreement with measured data and encourage commercial application of developed framework.

The dry sulfur-removal process is essential to provide suitable syngas treatment for the oxy-fuel integrated gasification combined cycle power generation plant. It is required to be durable to the carbon deposition due to syngas containing high concentration of carbon monoxide in addition to achieve sufficient performance for sulfur removal. Zinc ferrite, as the most promising candidate for the dry sulfur-removal process, was improved by Kobayashi and Akiho [12]. The improved sorbent was prepared from sulfates as the raw materials was evaluated on the performance and carbon deposition tendency in oxy-fuel syngas condition in a fixed bed reactor at elevated pressure and temperature. The results showed that the improved sorbent has higher desulfurisation performance and durability to carbon deposition in the condition expected for cyclic operation of the sulfur-removal process in comparison with the former sorbent. The results confirmed the enhanced feasibility of the dry sulfur-removal process by utilizing the improved sorbent.

Energy Efficient Technologies

At the same SDEWES conference where Prof. Carvalho presented how to build the low carbon society [2], Akashi et al. [13] showed the importance of research on future trends in emissions from the industry and possibilities for their reduction potentials in order to make a plan for low carbon society. Besides fuel switching, the efficient use of energy is important for the decarbonisation of the industrial sector and many authors have addressed this issue in previous SDEWES conferences. Energy efficiency, efficiency of energy transformations and energy recovery should be insured to avoid unnecessary entropy production but also to make processes more cost effective and environmental friendly. Thus, optimising heat exchangers in industrial processes have been prioritised by many SDEWES authors. Recently, Pintarič et al. [14] presented a robust computational methodology for the synthesis and design of flexible HEN (Heat Exchanger Networks) having large numbers of uncertain parameters. Their methodology combined several heuristic methods which progressively lead to a flexible HEN design at a specific level of confidence. Previous work on HEN was also focussed on optimization approaches for improving energy recovery in retrofitting HEN as showed by Pan et al. [15], optimization of the entire life economy of HEN given by Nemet et al. [16] and simultaneous synthesis of process water and HEN by Ahmetovic and Kravanja [17]. Moreover, pinch or similar methods have been used to optimise HEN. For example, Zhang et al. [18] reported on sustaining high energy efficiency in existing processes with advanced process integration technology while Boldyryev et al. [19] provided a methodology for decreasing the capital cost for Total Site heat recovery by use of different utility levels. Wan Alvi et al. [20] presented an approach that considers heat losses and heat gains during the establishment of minimum utility targets.

Although optimization of HEN is important, it is also essential to optimize the design of a single heat exchanger. Previously, the influence of plate corrugations geometry was researched by Arsenyeva et al. [21]. The authors developed a mathematical model of plate heat exchanger (PHE) using decomposition of the plate on its main corrugated field, which cause a major effect on heat transfer, and distribution zone, which influences mostly the hydraulic performance. Model is validated on experimental data for some commercial plates. Heat transfer intensification for shell and tube heat exchangers was presented by Pan et al. [22], while Ma et al. [23] studied local thermal–hydraulic performance and optimization of zigzag-type printed circuit heat exchanger at high temperatures up to 900°C. Masiukiewicz and Anweiler [24] described a method of two-phase flow structure evaluation for minichannels of mini heat exchangers and concluded that for each flow structure there is a set of stereological parameters, enabling the quantitative estimation of the two-phase flow. They also found out that the interrelation of stereological parameters, during the change of the flow structure, can be used for controlling the operating conditions. Wang et al. [25] presented review of three kinds of surface heat exchangers, i.e., shell-and-tube heat exchangers with helical baffles, air-cooled heat exchangers used in large air-cooled systems, and primary surface heat exchangers. At prior SDEWES conferences there were also many papers representing optimisation of heat recovery and HEN design for a single plant or facility as showed by Anastasovski et al. [26] for analysis of heat recovery system in a bioprocess plant.

It is clear that research in heat exchangers and HEN were the important topics at previous SDEWES conferences. In the current special issue, several papers also addressed the problem of efficient and cost effective heat exchangers. In the current issue, Ma et al. [27] described the Cross-Wavy (CW) primary surface heat exchanger as one of the most promising candidates for microturbine recuperators. Authors conducted naphthalene sublimation experiments to investigate the heat transfer and pressure drop performance in CW primary surface channels. The effect of equivalent diameters on the heat transfer and pressure drop performance of the CW primary surface channels was studied by numerical simulations. They concluded that the entrance region has a small effect on the unit-averaged heat transfer coefficient of the whole CW channel. The distributions of the local heat transfer coefficient in one repeated unit are different at different Reynolds numbers, because the location of the point of reattachment and the size of the recirculation zone changes as the Reynolds number changes. Developed numerical model with the multi-periodic boundary conditions and the linearly decreasing wall temperature boundary is suitable for numerical simulations of the CW primary surface channels. Authors also found out that friction factor obtained from the enlarged CW channels are suitable for the prediction of similar CW channels with the small size.

The current SDEWES special issue presents numerical simulation and experimental verification of heat transfer from a finned housing of an electric motor that has been studied by Grabowski et. al. [28]. Authors investigated heat conduction in the finned housing of an electric motor and compared results of numerical analysis with an experimental data to verify the suitability of numerical simulation as an engineering tool for motor design improvements. 3D geometrical model of the motor rated 7.5 kW was imported to COMSOL Multiphysics software package to investigate the temperature distribution. Measurements were carried out using FLIR SC7600 thermovision camera and steady-state temperature distribution on the surface of housing of the motor run in idling conditions was recorded. Relative differences between simulated and termographically measured temperatures of the fin surface did not exceed 10% after which authors concluded that the temperature distribution may create a convenient basis for structural analysis of the housing accounting for thermal stresses.

Previously, Ruelas et. al. [29] developed and applied a new mathematical model for estimating the intercept factor of a Scheffler-type solar concentrator (STSC) based on the geometric and optical behaviour of the concentrator in Cartesian coordinates, and the incorporation of a thermal model of the receptor is performed using numerical examinations to determine the technical feasibility of attaching the STSC to a 3 kWe Stirling engine. Authors used numerical simulations and experimental data to validate the mathematical model. Another numerical study of heat exchangers including solar concentrators is presented in the current special issue. The study provided by Przenzak et al. [30] concerns a high temperature heat receiver, which is a part of a concentrating solar radiation helio-energetic installation. Authors modified ray-tracing method to determine the best location for the absorber within the focal points. To conduct simulations maps and graphs of the distribution of absorbed radiation intensity were obtained and used as a second-order boundary condition in the modelling task, i.e. in simulations that allow for analysis of basic parameters of the medium. The study was based on computational fluid dynamics (CFD). Surface and spatial distribution of temperature in the heat receiver and the changes of medium temperature, among others, were presented in the article. The conducted research contributes to optimizing the concentrating solar radiation system and to increase the efficiency of the high-temperature heat receiver.

Another work in the field of simulation and modelling of heat exchangers using CFD in the current SDEWES special issue is performed by La Madrid et. al. [31]. The paper presents a numerical simulation of heat transfer phenomena in the open heat exchangers used in a Jaggery production. The Jaggery (also called organic sugar) is a concentrated product of sugarcane juice that is produced in rural communities in the highlands and jungle of Peru. Open heat exchangers made of stainless steel are used in the production of jaggery. These heat exchangers containing sugarcane juice are placed over a flue gas duct. The results of the numerical simulation of heat transfer phenomena in the open heat exchangers are compared to field measured data. Numerical results about temperature drop of flue gases in the several locations of the jaggery furnace are in good accordance with field measurements, validating the predictive capacity that the constructed 3D CFD model offers in the detailed representation of the fluid flow and heat transfer characteristics. Presented CFD model will ensure the design of future jaggery installations with higher thermal efficiency and sugarcane production with possibility to achieve energy self-sufficiency of the plant causing a minor environmental impact by preventing the burning of wood and deforestation.

There are many places in the urban environment where heat can be recovered. Integrated approach allows to simultaneously achieve energy savings and environmental benefits that are not only represented by reductions in GHG emissions. In the current special issue, Tańczuk et al. [32] optimized size of a waste heat recovery unit for a municipal sewage sludge drying plant supplied with heat generated in CHP units fuelled with natural gas. Drying of digested sewage sludge, as an important alternative to sludge disposal at dumping sites, should comply with the requirements of high energy efficiency as well as economic feasibility. The technical and economic optimization analysis of installing a waste process heat recovery unit in a medium-temperature belt dryer operated in a municipal waste water treatment plant was carried out. Inlet capacity of the plant is 1.83 Mg of wet sludge per hour. Calculated profitability of applying HED (heat exchanger in design) in the sewage drying plant supplied with heat generated in gas-fired CHP unit is very sensitive to the price of natural gas and less sensitive to the electricity price. While up to 683 MWh/y of chemical energy savings for optimal heat exchanger size could be achieved it is important to show that optimal system sizes regarding Net Present Value and Net Present Value Ratio do not coincide. A higher profitability for the larger heat exchanger cases has been calculated and is equal to paybacks below 3.65 years. The authors concluded that it is important for the investors to use both feasibility criterions. Other conclusions are more general as they proved that higher fuel prices allows higher investments in energy recovery systems while for a low-cost fuels (such as e.g. the dried sludge waste), investing in energy efficiency may be not economically justified, in spite of equally positive energy effects.

Sustainable Buildings, Campuses and Communities

The building sector is another sector that is in urgent need for the more efficient management of energy resources. Global energy consumption of the buildings sector was almost 120 EJ, or over 30% of total final energy consumption for all sectors of the economy [33]. Since 2000 energy use in building sector has risen almost for 20% while currently buildings account for half of global electricity demand [33]. As mentioned earlier buildings were responsible for 6% of global CO_2 emissions [1] but according to [33] when upstream power generation is taken into account, the buildings sector represents nearly 30% of global CO_2 emissions. Solutions at the building level may also be integrated with solutions at various levels of the built environment, including the building cluster, district, and city levels.

In a future outlook, as explained by Prof. Carvolho [2], buildings in future energy systems should be energy positive which means that they can generate more energy than they consume within a certain timeframe, usually over one year. Currently, there are many low energy buildings or nearly zero energy buildings in the market, with cost effective construction and use. Besides energy positive buildings it is possible and recommendable to define energy positive neighbourhoods in order to set a wider framework for transformations of current cites and urban zones to carbon neutral ones. This will also be beneficial to asses possibilities for local developments in the form of energy efficiency and heat recovery as well as new installations for the supply of renewable energy.

Previously at SDEWES conferences, net-zero and/or energy positive neighbourhoods or city districts were defined by Kılkış, [34] in which the Rational Exergy Management Model was used to match the grade/quality of energy resources (exergy) on the supply and demand sides. The author also defined the concept of net-zero exergy districts as one which produce as much energy at the same grade or quality as consumed on an annual basis. Finally, analysis of 5 scenarios was conducted based on a Net-Zero Exergy District Option Index. According to the results, a pilot concept for the first phase of the project was proposed. This integrated a mix of 8 measures considering an annual electricity load of 46.0 GWh_e and annual thermal load of 67.0 GWh_t. The work on net-zero districts was extended by Kılkış, [35] where a 4 step approach for the design of net-zero exergy districts was proposed. The problem was also addressed at the city level [36] as in the case study for the city of Bologna's energy system transformation by 2050. The authors proposed a method that combines a bottom-up disaggregation of energy demands by fuel type and end-uses at sub urban level with the simulation of a large number of discrete long term alternatives. The best options found by the authors could reduce Bologna's final energy consumption by 52% and its CO_2 emissions by 83.5% [36]. Within the multi-disciplinary approach of the SDEWES conferences, a special session on Sustainable Campuses and Communities: Living Labs of Future Production and Consumption Systems was organised to highlight the role of campuses in spearheading the drive towards future production and consumption systems. As centres of educational and research excellence, campuses and faculty buildings are further in a unique position to offer the built environment as "living labs" for the pilot application of measures to increase the sustainability of a certain building cluster, area or city. The special session was organised by Dr. Şiir Kilkiş from the Scientific and Technological Research Council of Turkey (TÜBİTAK). Some of the presented papers from the special session were selected for publishing in the current special issue.

In this context Ala-Juusela et al. [37] provided and described an explicit definition of the conception of energy positive neighbourhood in the framework of a European project IDEAS – Intelligent NeighbourhooD Energy Allocation and Supervision. Within the same project, the authors developed technologies and business models required for the cost effective and incremental implementation of energy positive neighbourhoods. Moreover, the authors demonstrate the theory with the ultimate goal to support the integration of distributed renewable energy generation into wider energy networks and provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible, which is meaningful to the field of environment and energy. Authors also proposed a series of indictors for measuring local energy supply and demand balance. Furthermore, the two pilot sites for the IDEAS project in Finland and France have shown concretely that more futuristic scenarios will require a re-appraisal between the cost and storage of the local energy supply. In addition, an energy positivity label is presented to enable the visualisation of the progress of an area towards becoming energy positive. In doing so, it extends the system limits of current approaches to energy analysis for urban sustainability. The energy positivity level of an area is estimated with calculating energy matching indicators: on-site energy ratio, annual mismatch ratio and other mismatch indicators.

Contrary to the labelling of districts which is a novel proposal given by Ala-Juusela et al. [37], the certification and eco –labeling of buildings has been studied by many authors. Previously, Franzitta et al. [38] described holistic and by-components approaches to European Eco-label brand for residential buildings, while in the same SDEWES special issue Malmqvist at al. [39] described a Swedish environmental rating tool for buildings and with the other group of co-authors Malmqvist at al. [40] provided methods and guidelines for Life cycle assessment (LCA) in buildings. More work on classification and energy consumption of large residential buildings stocks was provided by Filogamo et al. [41]. The authors provided a method for the disaggregation of a given building stock into proper typologies that are representative of the different construction practices characterizing different periods of time. The climatic properties of sites are accounted for in this methodology as well. Furthermore, the whole energy consumption is assessed using different approaches for heating, cooling, lighting and other electric appliances. This multiple approach depends on statistical data and on the application of well established calculation tools for the energy demand of buildings. The authors further defined a sample of buildings as representative of the considered building stock. The method was applied to the entire building sector of the Sicilian Region and validated for the year 2011. To put a focus on a particular set of buildings, Singh et al. [42] studied for the indoor thermal environment monitoring including 20 residential buildings of Liege city. It was found that glazing of windows has a minimum or an adverse effect on the existing indoor environment due to the absence of proper insulation of the rest of the building envelope. It was observed, that in winter there is a sudden drop in indoor temperature and also overheating in summer. Similar to the analysis of energy consumption of residential buildings, Chung and Park [43] provided an analysis of energy demand collected by survey and measurements throughout Korea to establish load models for three types of buildings: hotels, hospitals, and offices. Key statistical values such as the annual mean, maximum, and minimum values were provided. Their load models can be applied to a wide range of problems in building energy system design and planning, including simulations and optimizations of community energy systems.

In their previous works Kovacic et al. [44] provided the possible approach to the optimisation of the building construction. They showed that the early building design phases play a crucial role for the determination of building's life cycle performance in terms of resources and energy consumption and development of LCC (life cycle costs). Optimization potential is still very large in this stage and interventions could be planned at very low cost. In the latter planning such as construction and renovation phases, the change possibility rapidly decreases with simultaneously increasing costs. Using a case study of an energy efficient building, LCC were assessed employing the three tools and the deviations of the results were compared to help planners and investors to optimize their assets. Similar conclusions were provided by Russell-Smith [45] et al. as they combined LCA and target value design (TVD) to rapidly produce more sustainable building designs. By establishing site-specific sustainability targets and using dynamically-updating LCA, they demonstrated that buildings can be designed to perform at higher environmental standards than those designed without a target in place. Their paper analysed the trade-offs between design and operational decisions. Previously, Kovacic et al. [46] also provided life-cycle based renovation strategies considering not only structural and thermal refurbishment, but also the social aspects of an ageing society needs, as well as a preservation of cultural heritage.

In the current special issue, Herrando et al. [47] present the Energy Performance Certification process, according to the transposition of Directive 2010/31/EU, for 21 Faculty Buildings located at the University of Zaragoza (Spain), focusing on the assessment of the discrepancies between the estimated (simulated) energy consumption and the actual energy consumption (reported at Utility Bills). The energy consumption breakdown by uses for several buildings has been analysed and it has been concluded that the final energy consumption for both Academic and Research buildings have a similar energy performance with an average of 83 kWh/m^2-year. The main contribution of their work concerns the evaluation of the causes and potential solutions for the energy performance gap between estimated and real energy consumption. Authors also analysed the main difficulties and discrepancies found in the implementation of the buildings and they proposed potential improvements in the simulation software to shorten this gap. One of the factors that is responsible for the energy performance gap is the energy consumption of IT and laboratory equipment, especially in the case of Research buildings, as these equipment cannot be implemented in the tested software. Another important issue is that the users behaviour is very difficult to implement in a simulation tool, mainly due to their unpredictable nature. The discrepancies between the estimated and the real energy consumption could also be reduced by implementing more realistic operation schedules. The authors concluded that energy efficiency measure that should be always considered in the first place is to raise the user behaviour awareness.

In a previous SDEWES special issue, Marinakis et al. [48] presented an integrated system for buildings' energy-efficient automation. Their system was based on a prototype software tool for the simulation and optimization of energy consumption in the building sector, enhancing the interactivity of building automation systems. The tool can incorporate energy-efficient automation functions for heating, cooling and/or lighting based on guidance and decisions of the National Law, energy efficiency requirements of EN 15232 and ISO 50001 Energy Management Standard among others. Authors used a supermarket building in Greece as a test case for their approach with particular focused on the remote control of active systems.

In current SDEWES special issues, Horvat and Dović [49] present a new approach for the estimation of buildings technical system energy performance. The authors developed new methods consisting of a mathematical model for accurately prediction of indoor temperature and heat losses of the space heating and domestic hot water system components. The entire model is described by system of ordinary differential equations which can be solved using standard numerical techniques. Presented model can also be used for energy performance calculations in a wide variety of buildings types and their technical systems. As a test case authors used a family house, equipped with conventional space heating and DHW system, with the time step of 1 minute and for characteristic day of each month within a year. The results are compared against those obtained from EN ISO 13790 and standard series EN 15316. Similar to Herrando et al. [47], the comparison shows significant differences in determination of the annual delivered energy to the heating system (33%), as a consequence of the difference in estimation of the energy need for heating (15%) and calculation of the technical systems recoverable heat losses utilization factor, which seems to be underestimated. The delivered energy to the space heating and DHW system differs by 25%.

Previously, Berković-Šubić et al. [50] presented a method based on the energy performance of buildings Directive (EPBD) related European norms for analysis of the influence of particular system components on the overall system energy efficiency. The test case was a Croatian reference dwelling, equipped with a solar hot water system, backed up with a biomass boiler for space heating and domestic hot water purposes as part of the dwelling energy performance certification. Another environmental assessment of domestic solar hot water systems has been provided by Zambrana-Vasquez et al. [51].

In the current special issue Calise et al. [52] provide thermoeconomic optimization of a solar-assisted heat pump based on transient simulations and computer design of experiments. The plant simulation model based on TRNSYS is designed to supply electricity, space heating or cooling and domestic hot water for a small residential building. The system consists of a solar field equipped with flat-plate photovoltaic/thermal collectors, coupled with a water-to-water electric heat pump/chiller. The electrical energy produced by the hybrid collectors is entirely supplied to the building. The results showed that thermal and electrical efficiencies are above 40% and 10%, respectively. The Coefficient of Performance of the reversible heat pump resulted above 4 for both heating and cooling modes. For the base case, a Simple Pay Back period of 5.36 years was found.

Sornek at al. [53] present original results in the field of determining the possibility of the use of a thermoelectric generator to achieve self-sufficient operation of the stove-fireplace with accumulation. Results provide good basis for developing a micro cogeneration system powered by renewable energy sources. The maximum power of the generator would not exceed ca. 30 W_e and currently there is no economic justification for such a device. In presented units, the temperature of the flue gasshould should be kept at a certain level for the purposes of storing heat, which results in certain limitations for the thermoelectric generators. Three types of heat exchangers were studied and the most efficient unit was selected for further testing. Two types of thermoelectric generators, with maximum operating temperatures of 320 °C and 175 °C were compared. The introduction of a comparative temperature coefficient was useful to compare different variants of the heat exchanger's construction. The efficiency of the power generation is strongly dependent on the heat transfer from the flue gas to the hot plate of thermoelectric module and from the cooling medium to the cold plate of thermoelectric module. The proper selection of thermoelectric module working temperature has a great impact on its efficiency.

Trigeneration systems could provide self sufficiency for buildings or neighbourhoods and cities so it is important to optimise the size of equipment, construction and operation strategies. Previously, Usón et al. [54] presented thermoecological evaluation of a trigeneration module based on an Internal Combustion Engine fuelled with selected fuels of various origin. Another optimisation of trigeneration system for a building sector was previously addressed by Piacentino et al. [55]. The authors provided an upgrade for the software that simultaneously optimizes the plant layout, the sizes of the main components and their operation strategies. Optimization of trigeneration plant and its economic viability related with external conditions like energy prices and support mechanisms was also addressed previously in [56] and [57]. Authors in [55] used a specific building in the hotel sector in order to identify the most promising plant configuration, in terms of the type of cogeneration unit (either microturbine or diesel oil/natural gas-fueled reciprocate engine) and absorption chiller. Similar configurations were proposed by Dominković et al. in [58]. Application of trigeneration systems in tertiary sector was proposed by Carvalho et al. [59] or as shown recently by Di Palma et al. [57] who provided an economic analysis of trigeneration systems through a calculation model developed for applications in the field of large retail sector. Furthermore, optimization problem of binary co-generative power plant with high temperature solid oxide fuel cells (SOFC) on solid fuel with a higher power was investigated in [60] while Rokni et al. [61] provided thermodynamic and thermoeconomic investigations of a small-scale integrated gasification SOFC and Stirling engine for combined heat and power (CHP) with a net electric capacity of 120 kWe. Woodchips are used as gasification feedstock to produce syngas, which is then utilized to feed the anode side of the SOFC stacks. A thermal efficiency of 0.424 (lower heating value) for the plant is found to use 89.4 kg/h of feedstock to produce the above mentioned electricity.

In the current SDEWES special issue, Angrisani et.al. [62] present an index framework for analysing performance of polygeneration energy systems, together with thermo-economic analysis and sensitivity analysis. Thermo-economic analysis is performed considering three small scale commercial cogenerators while the sensitivity analysis is performed considering different reference average values of electric efficiency, natural gas and electricity prices, and emission factors for some European countries. The paper also provides a review of the available indices and methodologies to assess the performances of polygeneration systems. The presented work started as an activity in the framework of the International Energy Agency Annex 54 project ("Integration of Micro- Generation and Related Energy Technologies in Buildings"), where the research group shared their expertise about the methods applied in each country to evaluate the performance of polygeneration systems. It was concluded that a thermo-economic analysis comparing the performance of a polygeneration system with those of a reference benchmark scenario, is a very suitable assessment method. The energy performance of a CHP can be significantly affected by its dynamic responses. Two cases studies were used to demonstrate the feasibility of the alternative system according to the high limiting value of the electric power generation efficiency for the CHPs considered with respect to the average values of separate electric production of the most of the European countries. According to the environmental analysis it has been established that combined production is more convenient for the countries in which the electric separate production is mainly based on fossil fuel, in particular for Slovenia avoided equivalent CO_2 emissions are equal to 47% and 82 % for Case Study 1 and 2, respectively. The 3-E analysis for the subcase of Case Study 2, has proved that the combined production of cooling and electric energy is not convenient, because of the recovered amount of thermal energy available from the CHPs is not totally used. For this subcase the energy analysis has demonstrated that the limiting value of the grid electric efficiency of the CHP 3 is lower than electric separate production efficiency of several countries.

Renewable Energy Technologies and Sources

Technologies for the better utilization of renewable energy sources will have a defining role in future energy systems. In this context, the current SDEWES special issue is also dealing with small scale hybrid applications for renewable energy utilisation. Slimani et al. [63] present a study on the modelling of the energy performance of a hybrid photovoltaic/thermal solar collector. The work can help researchers understand how the different configurations of hybrid PV/T air collector affect the thermal and electric performance. The thermal efficiency of the analysed hybrid collector increased by 30.85% compared to the standard configuration while the air temperature supplied by a double-pass photovoltaic/thermal collector is very suitable for solar drying. Authors provided a system of electrical and thermal balance equations and analysed governing various electric and heat transfer parameters in the solar hybrid air collector. The numerical model from their study gives a good precision of results, which are close to the experimental ones (of previous literature), and makes it possible to have a good assessment of energy performance regarding the studied configuration (temperature, electric and thermal powers, electrical and thermal efficiencies etc.). The numerical results show the energy effectiveness of the proposed hybrid collector configuration and novelty of use in an indirect solar dryer system that provides a more suitable air temperature for drying agricultural products. The values of the electrical, thermal and overall energy efficiencies reaches 10.5 %, 70% and 90% respectively, with a mass flow rate of 0.0155 kg/s and weather data sample for the month of June in the Algiers site. From this study, several conclusions have been drawn: The glazing of PV/T collector leads to an increase in the thermal performance and to a decrease in the electrical performance of the system. The average values of the thermal and the electrical efficiencies of the solar PV/T air collector evaluated with the operating conditions are 41.09% and 9.33%, respectively.

Previously, Zeigarnik presented problems in the development of CHP systems [64]. In the current SDEWES special issue, the energy potential of biomass from growing short rotation coppice (SRC) on unused agricultural land in the Republic of Croatia is used to investigate the feasibility of CHP facilities fuelled by such biomass [65]. Pfeifer et al. [65] analysed large areas of agricultural land that remain unused for food crops and concluded that they represent significant potential for growing biomass that could also be used for energy. In their studies they envisaged power plants of up to 15 MW_e in accordance with heat demands of the chosen locations. The methodology for regional energy potential assessment was elaborated in previous work and is now used to investigate the conditions in which such energy facilities could be feasible. The overall potential of biomass from short rotation coppice cultivated on unused agricultural land in the scenarios with 30% of the area is up to 10 PJ/year. The added value of fruit trees pruning biomass represents an incentive for the development of fruit production on such agricultural land. Sensitivity analysis was conducted for several parameters: cost of biomass, investment costs in CHP systems and combined change in biomass and technology cost. Cultivating SRC for biomass has already been commercially established in the value chains of some EU countries, especially in Sweden, Denmark, Germany, the UK, Poland and Italy. In the EU, research continues on the influence of SRC on soil, SRC yield and the best practices to exploit SRC for biomass as a valuable contribution to common energy and environmental goals in 2020 and beyond. In Croatia, SRC can be seen as a new fuel, which fosters the integration of factors such as large areas of unused agricultural land, high unemployment and renewable sources inclusion goals. Analysis of regional potential in [65] shows that even conservative assumptions on the area that could be cultivated with SRC could lead to the substantial contribution of meeting local energy demands in a more sustainable way and creating new job opportunities at the same time. At the moment, the most innovative approaches with the combined heating and cooling plants with seasonal storage are not the economically feasible way of exploiting biomass from SRC. More conventional CHP solutions would be feasible to implement.

Even high efficient cogeneration or trigeneration units should be applied whenever it is possible to maximise the utilisation of primary resources such as biomass, in many cases CHP units will not be economically feasible so wood boilers will still be applied. Previously, Mladenović et al. [66] proposed the biomass boiler concept for combustion of large soya straw bales. Different biomass fuels were tested by Duncan et al. [67] which proposed new biomass pellets and provided experimental tests of tensile strength, ultimate and proximate analysis, abrasion resistance, moisture sensitivity, and mass and dimensional characteristics. Combined pellet biomass and solar boiler was proposed and tested for apartment buildings in Latvia [68]. After small scale laboratory testing, the authors proposed optimisation of the 100 kW pellet boiler. Forbeas et al. [69] investigated the physical, chemical, thermo-gravimetric and combustion properties of eight different biomass fuels in a small scale multi-fuel boiler.

It is important to design efficient biomass boilers so Rajh et al. [70] presented in the current special issue advanced modelling and testing of a 13 MWth waste wood-fired grate boiler with recycled flue gas. As previously shown numerical modelling is widely used in industry for detailed understanding of the combustion process and for appropriate design and optimization of biomass/waste-fired boilers. Authors here present a numerical study of a 13 MWth waste wood-fired grate boiler, based on the coupled in-bed fuel conversion modelling and freeboard combustion modelling method. A 1D model is developed for the conversion of the waste wood in the fuel bed on the grate, providing the appropriate grate inlet condition for the 3D simulation of the freeboard region. Since part of the flue gas is recycled into the boiler as an innovative attempt to improve the boiler performance, a refined weighted-sum-of-grey-gases-model of greater accuracy is developed to better address the impacts of the elevated CO_2 and H_2O vapour concentrations on radiative heat transfer in the boiler. The impacts of full buoyancy on the turbulent flow are also investigated. The temperature profiles at different parts in the furnace are measured to shed some light on the flow and combustion characteristics in the boiler and also to collect some in-flame data for modelling validation. The overall modelling strategy, the new sub-models and the use of recycled flue gas are all of great benefit or reference for modelling and design of grate-fired boilers.

Biomass as a substitution for coal has been recognized as a CO_2 mitigation option by many SDEWES participants. There are even several boiler types that can accept various fuels, biomass co-firing must be optimised for each one to have similar or better efficiencies. Previously, Kazagic and Smajevic [71] investigated synergy effects of co-firing wooden biomass with coal from Bosnia and Herzegovina, while Smajevic et al. [72] presented results of experimental studies on a laboratory-scale furnace and 110 MWe power unit. Authors provided evidence for certain benefits in co-firing of biomass until 7%/wt of brown coal was replaced with sawdust. There were also no risk to the efficiency decrease and negative impacts to the combustion process. Furthermore, they showed that no modification to the existing coal transport system and boiler equipment is necessary to achieve reported outcome. Kuprianov et al. [73] also researched effects of operating conditions and fuel properties on emission performance and combustion efficiency of a swirling fluidized-bed combustor fired with a biomass fuel, while similar studies have been conducted by Mehmood et al. [74] where authors used simulation of combinations based on two coals (bituminous coal, lignite) and four types of biomass (rice husk, sawdust, chicken litter, refused derived fuel). They concluded that net CO_2 emissions should decline significantly, while the reductions in emissions of nitrogen and sulphur oxides are dependent on the contents of nitrogen and sulphur in the biomass. Comparison of cofiring and biomass combustion by LCA method is provided in [75] where authors concluded that a 29% net electric efficiency biomass-fired power plant would be required to achieve the same global GHG emissions decrease as biomass cofiring. Recently, Moiseyev et al. [76] studied the substitution of coal with biomass as a CO_2 mitigation option at the EU level while Hoffmann et al. [77] studied the co-combustion of coal and eucalyptus.

Investigation of short rotation biomass as source of fuel for CHP units has been already addressed in this issue in in Pfeifer et al. [65], while previously Kuppens et al. [78] proposed willow trees cultivated in short rotation to serve as a phytoextracting crop to be used in the fast pyrolysis as it has lower process temperature that prevents metal volatilization. In the current SDEWES special issue, Pereira et al. [79] researched the potential of poplar short rotation coppice cultivation for bioenergy in the Alentejo region of Southern Portugal. Using cofiring technology, the biomass should be co-fired up to 10% (energy basis) with other fuels at two Portuguese coal-fired power plants (Sines and Pego). The study considers the overall production chain from cradle to power plant gate, cultivated in scrubland areas with duration of 12 years, harvested every three years and with 6,667 plants per ha, covering a land area of about 52,250 ha. Three different biomass annual yields are assumed. The results show that the biomass selling prices range from 76.9 to 120.5 Euro ton−1, to match the production costs. The net energy of the overall project ranges from 34.7 to 75.4 PJ and the project cost from 619 to 823.9 MEuro. The main environmental impact of the project is the reduction of the CO_2 emissions due to the biomass cofiring, instead of burning coal alone. The power plants can reduce CO_2 emissions over the project lifetime between 8.2% and 16.5% of the current values. The financial analysis demonstrates that the project is not financially feasible without external grants, but a policy scenario of carbon allowances trading may be instrumental on turning it to a financially feasible, depending on allowances and coal market prices. Finally, with a reduction of 50% in the main costs, the project becomes financially feasible under a CO_2 emissions trading scenario for a biomass yield of 20 dry ton ha−1 per year.

Besides application in power and heat generation biomass can be effectively applied in the industrial process. Using biomass for partial or complete replacement of coke breeze in the iron ore sintering process is an attractive technique for reducing emissions of greenhouse gas and gaseous pollutants. In the current SDEWES special issue, Cheng et al. [80] studied commercial charcoal made from sawdust, nutshell and some other waste biomass (with extensive source and low cost) as an alternative fuel in the sintering process. The primary fuel was coke breeze with 20%, 40%, 60%, 80% and 100% substitution of the fixed carbon input with charcoal. The flame front characteristics and sintering performance were compared at different substitution rates. The results indicated that the flame front accelerated with the increase of charcoal substitution rate due to its higher intrinsic reactivity and larger specific reaction area. Both duration time of melting temperature and melt quantity index reached their peak values at 60% charcoal substitution rate. When the substitution rate exceeded 60%, duration time of melting temperature and melt quantity index dropped sharply, suggesting that the sinter strength was deteriorating. Reasons for the weakened sinters were analysed from the views of combustion efficiency (heat generation) and heat accumulation performance (heat utilization). NO_x emission concentration reduced significantly with the increase of charcoal proportion. Authors also made suggestions for improving charcoal sintering performance. To maintain high sinter strength, the excessively high combustion rate at high charcoal proportion may be avoided.

Several technologies are available to convert various biomass feedstocks into heat, electricity and fuels. The most widespread method includes direct combustion which is elaborated in the current special issue, while other methods are gasification, pyrolysis, hydrolysis, reforming and anaerobic digestion. Even for bigger facilities, mass burn or combustion is the most common method as it directly combusts biomass with minimal processing using technologies, such as fixed-bed furnaces or fluidised-bed systems. For biomass combustion systems, flue gas treatment measures have to be implemented to minimise air pollution. Thermal gasification and pyrolysis include decomposition of biomass at a high temperature with small amount or no oxygen to generate a synthesis gas. The produced synthesis gas can be used after clean-up of the gas for the production of electricity, heat, various fuels or chemicals. Flexibility in the uses of the resulting synthesis gas is one of the advantages of gasification over combustion. Regardless of advantages of gasification technologies over other processes, they are still under development while investment costs for plants using gasification biomass technologies are estimated to be twice as high as commercial-scale advanced biofuel plants using hydrolysis- and fermentation-based technology [81].

Biogas and synthesis gas are important renewable energy sources that can be used in many applications and can also substitute natural gas. Previously, Orecchini and Bocci [82] reviewed processes and papers that showed how biomass hydrogen production can be utilised for closed cycle energy resources. Gasification in large scale application has been addressed previously by Klimantos et al. [83] and subsequently, improvement in gasification of biomass has been addressed by Khan et al. [84] who investigated the integrated catalytic adsorption steam gasification of palm kernel shell for hydrogen production in a pilot scale atmospheric fluidized bed gasifier. Mikulandrić et al. [85] and Mikulandrić et al. [86] provided improvements in biomass gasification process in fixed bed gasifiers. Sriwannawit et al. [87] recently addressed viability of biomass gasification systems in Indonesia.

Papers in the current special issue advance such studies. Mikulandrić et al. [88] analysed the potential of neural network based modelling to predict process parameters during gasification plant operation with variable operating conditions. Dynamic neural network based model for gasification purposes was developed and its performance was analysed based on measured data derived from a fixed bed biomass gasification plant operated by Technical University Dresden (TU Dresden). Dynamic neural network can predict process temperature with an average error less than 10% and in those terms, performs better than multiple linear regression models. Average prediction error of syngas quality is found to be lower than 30%. The developed model is applicable for online analysis of biomass gasification process under variable operating conditions. The model is automatically modified when new operating conditions occur. Modelling methods that have been used by the authors to develop the neural network prediction model are applicable for different kinds of gasifier designs.

As discussed before, biomass pyrolysis can be used to extract various compounds from different type of biomass. Previously, Medrano et al. in [89] proposed to use catalytic steam reforming in fluidized bed to produce hydrogen from aqueous fraction of biomass pyrolysis liquids. Opatokun et al. [90] assessed the energy potential of food waste energy harvesting system (digestion followed by pyrolysis of digestate). Digestate with increased calorific content was produced after a commercial one stage anaerobic digestion of the raw food waste. Authors concluded that transitional energy base products (biogas and bio-oil) are generated through the energy harvesting system of food waste, while energy rich solid fuels can be produced through pyrolysis at 500 °C.

In the current special issue, Kim et al. [91] proposed the thermal and ex-situ catalytic pyrolysis of different citrus peels. Four types of peels were studied by thermogravimetric, evolved gas analysis–mass spectrometry and tandem micro-reactor–gas chromatograph/mass spectrometry analyses. Kinetic analysis revealed more complicated reaction steps and a wider range of activation energies of citrus peels than those of wood powder due to the presence of pectin in the citrus peels. Large amounts of methanol formation from each citrus peel were also recorded by evolved gas analysis–mass spectrometry and fast pyrolysis–gas chromatograph/mass spectrometry analyses at the main decomposition temperature of pectin, between 150 and 250 °C. Mesoporous MFI was found to be a more effective catalyst for the production of mono aromatic compounds (benzene, toluene, ethylbenzene, and xylene; 3.06–4.17 C%) and light olefins (ethene, propene, butene, and butadiene; 8.13–9.13 C%) than Al-MCM-41 (mono aromatic compounds 0.67–0.93 C% and light olefins 3.61–4.58 C%) because of its higher catalytic activity in deoxygenation and aromatization due to the stronger acidity of mesoporous MFI.

Ferreiro et al. [92] provide, in current issue, study with a two-step fitting procedure to estimate the kinetic parameters of two distinct pyrolysis models to study the pyrolysis of pine bark, wheat straw and rice husk. Thermogravimetric curves were obtained for the three biomass fuels for heating rates of 5, 10 and 15 K/min in an inert atmosphere of Argon to investigate the impact of the type of biomass in the pyrolysis behaviour under different heating conditions. Distinctive thermogravimetric and differential thermogravimetric curves were obtained owing to the different composition of the biomass fuels. For the conditions examined, the impact of the heating rate on the profile curves was marginal. In order to better understand the impact of the biomass composition in the pyrolysis, their main components were estimated. Additionally, a two-step algorithm was used to calibrate the global kinetic parameters of a single reaction model and of a three parallel reaction model, based on the fitting of predicted curves to the experimental ones. The first step was a genetic algorithm procedure. An evaluation function that minimizes the deviation between the experimental and predicted pyrolysis yields, while preserving the characteristics of the mass decomposition during pyrolysis, is presented in this work. The second step was a least squares minimization that was used for further refining the solution obtained in the first step. The method showed excellent repeatability. For each biomass fuel, all heating rates were globally fitted, with errors of the order of ∼5% for the single reaction model and less than 1.6% for the three parallel reaction model.

The special issue continues with related topics that further underline the importance of the sustainable development of energy, water, and environment systems for future energy technology and concepts. Biogas production from wastewater treatment plants was studied by Nadais et al. [93], while some other works showed that biogas production from waste is the best option for waste management. Pubule et al. [94] used an effective tool to assess, compare, and select the best biowaste management alternatives for stakeholders in three Baltic States – Latvia, Lithuania and Estonia. The results obtained showed that separate collection and Anaerobic Digestion of biowaste is the best solution in all three Baltic States. Mondal and Banerjee [95] showed biogas production from organic fraction of municipal solid waste of Varanasi, India. A study by Nowak et al. [96], analysed the municipal wastewater treatment plant. The study showed that in advanced municipal wastewater treatment plants with nutrient removal, the total consumption of electric energy is smaller than the energy production by means of CHP generation using biogas from anaerobic sludge digestion. The potential of Organic Rankine Cycle (ORC) systems to retrofit CHP plants in wastewater treatment plants was analysed by Chacartegui et al. [97]. The heat available in the exhaust gases of the reciprocating engine is at a very high temperature (around 650 °C), while the temperature at which heat is needed for the digestion of sludge is around 40 °C. The huge temperature difference offers an opportunity to introduce an intermediate system between the engines and the digesters that makes use of a fraction of the available heat to convert it into electricity.

In the current special issue, Grosser and Neczaj [98] investigated how co-digestion of sewage sludge with other organic waste (for example fat rich materials) can enhance the performance of anaerobic digestion. They studied the effects of adding fatty rich materials on the performance and stability of semi-continuous anaerobic digestion of sewage sludge. Tests were conducted in laboratory conditions with different mixtures of the grease trap sludge. The results of the study indicate that the addition of fat rich materials like grease trap sludge can lead to a satisfactory increase in biogas yield in digester treating sewage sludge. Co-digestion can enhance the biogas yield by 28–82% compared to anaerobic digestion of sewage sludge alone (control sample). Moreover, the addition of grease trap sludge to digesters resulted in increased volatile solids removal from 44.38% (control sample) to 57.77% (feedstock with 14% addition of grease trap sludge). The results of the present laboratory study revealed that the use of grease trap sludge as a co-substrate is an interesting method for the intensification of methane production from sewage sludge [98].

Biogas can be used in the transport sector as substitute for fossil fuels so it is important to calculate the impacts of its use. Previously, Kozarac et al. [6] numerically analysed the influence of combustion product concentrations on the combustion characteristics (combustion timing and combustion duration) of a biogas fuelled homogeneous charge compression ignition (HCCI) engine. The authors also examined the possibility of reducing the high intake temperature requirement necessary for igniting biogas in a HCCI engine by using internal exhaust gas recirculation enabled by negative valve overlap. Similarly, the combustion efficiency was examined for spark ignition engines using biogas in [99].

In this SDEWES special issue, Matuszewska et al. [100] evaluate the biological methane potential of various feedstock for the production of biogas to supply agricultural tractors. They present results of biological methane potential of agriculture raw materials available in Poland and developed simple mathematical model of methanogenic fermentation. The data for this model are obtained from experimental digestion process of the chosen mixtures. They also present the results of exhaust emissions generated by dual-fuel engine of an agricultural tractor powered by a mixture of model biogas (60% and 70% of methane) and diesel oil. The obtained results reveal that there was a significant difference in chemical composition and yield of biogas between considered feedstock types. The highest biogas and methane production is obtained for mixtures in ratio of 6:4 for swine manure/maize silage and whey/grass silage. Due to agriculture conditions in Poland and the obtained results, the maize silage and swine manure are chosen for the development of the mathematical model of the fermentation process. Results of emission tests on the dual-fuel tractor engine that is supplied with biogas and diesel oil showed the higher concentrations of hydrocarbons and carbon oxide and lower concentrations of particulate matter in exhaust gases.

Previous studies such as those of Ridjan et al. [101] had identified potential pathways for producing synthetic fuels, with a specific focus on solid oxide electrolyser cells (SOEC) combined with the recycling of CO_2. In the current SDEWES special issue Wiesberg et al. [102] investigated two innovative chemical destinations of carbon dioxide to methanol, a direct conversion through carbon dioxide hydrogenation and indirect via carbon dioxide conversion to syngas through bi-reforming. Process simulation is used to obtain mass and energy balances needed to support assessment of economic and environmental performance. A business scenario is considered where an industrial source of nearly pure carbon dioxide exists and an investment decision for utilization of carbon dioxide is considered. Due to uncertainties in prices of the raw materials, hydrogen and natural gas, the decision procedure includes the definition of price thresholds to reach profitability. Sensitivity analyses are performed by varying costs with greater uncertainty, i.e., carbon dioxide and methanol, and recalculating maximum allowable prices of raw materials. Results showed that the integrated scenario of hydrogenation has an advantage of about 50

US$/t in the methanol price in comparison to its non-integrated alternative. The environmental analysis revealed that both routes contribute to reduce global warming potential, and the reduction is intensified with a clean energy source (hydropower), with additional environmental benefit of decreasing acidification potential. For fossil energy supply, hydrogenation succeeds to reduce 87% of the emissions from the carbon dioxide source (bioethanol plant). Moving to a clean energy scenario increases the efficiency to 98%. The bi-reforming scenario is unable to reduce emissions (rather increasing it by 105%) in the fossil based energy scenario, however, for clean energy supply, it emits only 46% of the input of carbon dioxide from the bioethanol plant.

Energy System Flexibility and Energy Storage

During previous SDEWES conferences, many researchers were successfully promoting different flexibility options for solving challenges to enable the high penetration of intermittent renewable energy sources (RES). The problem of flexibility was addressed for smaller standalone systems [103] which first reached high levels of RES share so authors promoted as solution hydrogen as an energy storage. Similar solutions were planned for bigger systems such as islands [104], where energy modelling tools were used to calculate different energy storage options to cope with the intermittency of renewable energy generation. Since it was showed that islands can also reach higher and even 100% shares of RES, flexibility was also examined for the national power systems. In the case of Ireland [105], authors extended version of an open source energy system model (OSeMOSYS) and showed requirements for operating reserve and related investments. Similar studies but with different models are provided by Gorm et al. [106] in the case of Denmark or Zakeri et. al for Finland [107]. In the case of Finland [107], the authors proposed a new index for assessing the maximum flexibility of energy systems in absorbing variable renewable energy. In their case, the maximum of wind energy can be harvested without major enhancements in the flexibility of energy infrastructure was at the levels of 18–19% of annual power demand (approx. 16 TWh/a). Previously, to work for the Finland published in 2015 [107], in 2008 Karlsson et. al. [108] had showed results calculated by the optimisation model Balmorel, adopted to the whole Nordic region. The authors found that the power system has a capacity deficit greater than 9 GW in 160 h a year and greater than 5 GW in 600 h a year. These results were calculated for higher installed capacities of intermittent energy e.g 80 GW wind power in the whole Nordic system in 2040 and a peak load power demand at the same system size. System flexibility was also addressed on the national level by Capuder at al. [109] where authors determined transmission lines requirements for the Croatian Power system in the case of large-scale wind power plant integration into the transmission grid in Croatia. An accurate and detailed model for assessing power flows and voltage levels has been developed. To show the flexibility needs and operation of the electricity market Higgins et al. [110] also used the national power system of Irland. They investigated the impacts of offshore wind power forecast error on the operation and management of a pool-based electricity market in 2050. The impact from offshore wind power forecast errors of up to 2000 MW on system generation costs, emission costs, dispatch-down of wind, number of start-ups and system marginal price were analysed. Among more recent results, Holjevac [111] analysed the effects of microgrids on the power system. This flexibility is analysed from two perspectives, defining two operating principles of each microgrid: independently from the distribution grid and connected, interacting and responding to signals from the upstream system.

The main goal was to quantify the ability of microgrid components to provide flexibility. Similar flexibility of power system and solution for energy storage was given by Batas Bijelic [112].

Having in mind previously published SDEWES papers [103] to [112] and impact of variable demand on the single power plant and its contribution to flexibility as given in [113], flexibility is still an important issue, maybe not any more for small cases as islands but more for national systems or for the whole interconnected systems of EU and neighbouring countries. The authors in the current SDEWES special issue presented new concept of backup flexibility classes in emerging large-scale renewable electricity systems. Schlachtberge et al. [114] quantify the changing demand for three backup flexibility classes in emerging large-scale electricity systems, as they transform from low to high shares of variable renewable power generation. A weather-driven modelling is used, which aggregates eight years of wind and solar power generation data as well as load data over Germany and Europe, and splits the backup system required to cover the residual load into three flexibility classes distinguished by their respective maximum rates of change of power output. The slowly flexible backup system is dominant at low renewable shares, but its optimized capacity decreases and drops close to zero once the average renewable power generation exceeds 50% of the mean load. The medium flexible backup capacities increase for modest renewable shares, peak at around a 40% renewable share, and then continuously decrease to almost zero once the average renewable power generation becomes larger than 100% of the mean load. The dispatch capacity of the highly flexible backup system becomes dominant for renewable shares beyond 50%, and reach their maximum around a 70% renewable share. For renewable shares above 70% the highly flexible backup capacity in Germany remains at its maximum, whereas it decreases again for Europe. This indicates that for highly renewable large-scale electricity systems the total required backup capacity can only be reduced if countries share their excess generation and backup power.

Energy storage can be beneficial to increase the flexibility of energy system as presented in many previous papers from SDEWES conferences for hydrogen and fuel cells [103], [104], [108] or pump hydro storage [115], but energy storage is also important for proper operation and cost optimization of single unit or facility. Previously Pavković et al. [116] presented the sizing of typical low-to-medium scale energy storage systems (up to 10 MW) based on flywheels, compressed air, batteries and ultracapacitors for prototype of high altitude wind conversion system. The assessment results are summarized in terms of investment/running costs, storage system size, and durability, thus providing practical guidelines for the selection of appropriate energy storage system. Contrary to some other storage proposals from previous SDEWES conferences as presented by Vynnycky [117] where chemical reactions are used to store energy, the electrochemical double layer capacitors (EDLC), known as ultracapacitors or supercapacitors are being proposed store energy in an electrostatic field ideally with no chemical reactions taking place are as studied and reported in the current SDEWES special issue [118]. EDLCs are characterised by large energy density compared with conventional capacitors due to a high permittivity dielectric, very large electrode surface area and extremely small charge separation. They have very low internal resistance and consequently have very high efficiencies, and allow very fast charge–discharge processes with high currents. Super capacitors can be completely discharged and can work in a wide range of environmental conditions. Supercapacitors have a considerably high power density but, conversely, present a relatively low energy density. Recent research on supercapacitors focuses on increasing their energy capacity by nanostructured materials and metal oxides. However, using these materials and processes are costly so in this SDEWES special issue, authors are proposing increasing supercapaitator energy capacity by usual porous carbon-based materials while reducing their price. Lee et al [118]developed an activated carbon with very high yield (80 wt.%) and higher capacity than commercial alternatives. In their work, pitch-based ACFs were prepared using different activation times in order to produce high specific-surface-area and mesopore-rich pore-structure. Specific surface area was increased with increasing activation time and burn off. The specific surface area surged from 1520 to 3230 m2/g and 0.61–1.87 cm3/g, respectively. The specific capacitance was confirmed to have increased from 1.1 F/g to 22.5 F/g. The authors also concluded that the pore characteristics of pitch-based activated carbon fibers changed considerably in relation to steam activation and charge/discharge cycle.

Heat storage is also beneficial and usually more cost effective for providing flexibility of power or district heating and cooling systems but also for optimisation of single plant. Chacartegui et al. [119] studied the integration of two heat storage layouts for small-mid size Organic Rankine Cycle Parabolic trough solar power plants (ORC-PTSPP). Full system performance at design and off design conditions is presented from thermal and economic points of view operating with different organic working fluids. The best results are achieved with 10 hours capacity of indirect thermal storage, while LCOE was reduced to 16.3 c€/kW. As solar field is the most expensive part of the plant and its dimensions can have significant impact on the LCOE, authors analysed 8 solar fields for their application with share of these fields in the total costs of plant between 43% and 63%. Potential application and main challenges for the development small scale ORC-PTSPP are discussed in terms of performance and costs. The presented results show the competitiveness of the proposed integrated solutions in small size parabolic trough designs for off grid solutions which can be further combined with other renewable technologies.

Chacartegui et al. [120] had further analysed the integration of a Humid Air microturbine and an ORC in a combined cycle for distributed generation. The analysis was also based on several sets of organic fluids and recovery temperatures. The results showed that the optimal integration was achieved using toluene and R245fa for the medium and low temperature ORC respectively. The ORC can be effectively applied for other renewable energy sources as previously described by Guzović et al. [121], where the geothermal power plant Velika Ciglena was taken as a case to assess comparatively a basic and a dual-pressure ORC or advanced options for ORC use together with SOFC [122].

As showed by Chacartegui et al. [119] beside solar field, energy storage can have a significant impact on cost and operation of solar power plants. Storing heat energy is important not only for solar projects but also for capturing and recovery of waste heat from industrial processes. However, before providing suitable high efficient storage solutions that will combine sensible and latent heat storage with phase change materials (PCMs) to provide a high energy density storage it is necessary to test if materials will withhold all stresses and will be safe for use. Previously in [123], authors discussed energy developments and storage techniques, with special emphasis on thermal energy storage and the use of PCM. They showed results obtained when encapsulating NaNO3/KNO3-PCM in an AISI 321 tube, as example of a storage application using a multi,-tubular exchanger filled with PCM. To increase the effective thermal conductivity of the PCM they planned insertion of metallic foam and metallic sponge. Based on experimental data and Comsol Multiphysics, they predicted the mechanical behaviour of the system and proved it will not lose stability under planned working conditions. In the current special issue, another contribution to the development of thermal energy storage technologies is provided by Urschitz et al. [124]. The authors proposed a novel bimetallic heat exchanger tube for a latent thermal energy storage application that can stand temperatures up to 340°C. Their solution can be applied in concentrated solar power plants and other heat exchanger tubes were fins, high temperature differences and high pressures are present. The authors further proposed the use of 4 prototypes 3 of which them are already in the state of the art while one is a completely novel solution. None of the prototypes described in the paper are used in the application of latent heat energy storage until now. The authors showed their solution for this problem is the bending ear that allows a flexible fin design and arrangement and probably can guarantee a good heat transfer through contact between the tubes. The study has to be seen as fundamental research for further investigations as it is focused only on the mechanical stability of the heat exchanger tube.

Conclusions

This introductory article was based primarily upon 32 papers selected from among 551 contributions presented at the 10th SDEWES conference. The papers have covered an extensive scope of technologies and concepts related to energy conversion and management approaches that have the potential to support future energy systems and post carbon society. These papers have also underlined the need for the sustainable development of energy, water, and environment systems in designing more effective and efficient solutions.

Even though presented papers in the current special issue are multidisciplinary and covers many aspects of sustainable development they have been grouped in five main topics. The papers under the topic Sustainable Combustion Technologies are selected from the SDEWES special session with same name and include Vujanović et al. [5], Sjerić et al. [7], Seljak et al. [8], Wang et al. [9], Baleta et al. [11] and Kobayashi and Akiho [12]. Most of them used numerical analysis of different combustion process, similar numerical analysis was also used for the papers presented under the topic Energy Efficient Technologies. Ma et al. [27], Grabowski et. al. [28], Przenzak et al. [30] and La Madrid et al. [31] use numerical analysis to asses heat exchange and to propose better design of heat exchangers while Tańczuk et al. [32] use the technical and economic optimization analysis to propose waste heat recovery system. Sustainable buildings, campuses and communities (building energy systems, energy positive sites, trigeneration and polygeneration) are represented by Ala-Juusela et al. [37], Herrando et al. [47], Horvat and Dović [49], Calise et al. [52], Sornek at al. [53] and Angrisani et.al. [62]. Many of the presented solutions for zero energy or energy positive buildings included some of renewable energy source or trigeneration system. These papers could also fit well under the fourth topic Renewable energy technologies and sources (solar, biomass sources, pyrolysis, biogas production, electrolysis) that includes papers Slimani et al. [63], Pfeifer et al. [65], Rajh et al. [70], Pereira et al. [79], Cheng et al. [80], Mikulandrić et al. [88], Kim et al. [91], Ferreiro et al. [92], Grosser and Neczaj [98], Matuszewska et al. [100], Wiesberg et al. [102]. The papers Rajh et al. [70], Pereira et al. [79] and Cheng et al. [80] have been also selected from the SDEWES special session Sustainable Combustion Technologies. The last topic Energy system flexibility and Energy Storage includes important papers for back-up flexibility Schlachtberge et al. [114] and energy storage Lee et al. [118], Chacartegui et al. [119] and Urschitz et al. [124].

The guest editors believe that the selected papers and addressed issues considerably extend the knowledge body published in Energy Conversion and Management and will be of interest to readers, including in the topics of sustainable combustion technologies, energy efficient technologies, sustainable buildings, campuses and communities, renewable energy technologies and sources, as well as energy system flexibility and energy storage.

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