Sustainable Development of Energy, Water, and Environment Systems

Subjects: Engineering, Environmental

Contributor: Maria da Graça Carvalho, Wenxiao Chu, Maria Vicidomini, Francesco Calise, Neven Duic, Poul Østergaard, Qiuwang Wang

Sustainability has become a broad societal goal, aiming to ensure that human beings coexist safely and harmoniously with nature over a longer time. The influence of the COVID-19 pandemic on the global economy is coming to an end. The development and merits of sustainable energy supply, advanced technology, and economic features have received significant attention over the past. Since 2002, the Sustainable Development of Energy, Water, and Environment Systems (SDEWES) conferences have become a significant meeting venue for researchers to introduce, discuss, share, and disseminate novel concepts and ideas.

Keywords: bioenergy ; hybrid system ; district heating and cooling

1. Introduction

Since 192 countries and regions joined the Kyoto Protocol, the United Nations Framework Convention on Climate Change entered into force in February, 2005 [1]. This provided a commitment that industrialized countries and economies that are in transition should limit and reduce greenhouse gas (GHG) emissions in accordance with agreed individual targets [2]. In June 2021, the European (EU) adopted the European Climate Law, the aim of which is to reach net zero greenhouse gas emissions (GHG) by 2050, which was reset in 2021 [3]. The law sets an intermediate target of reducing GHG by at least 55% by 2030 compared to the levels in 1990 [4]. A set of policies were proposed by the European Commission in order to achieve the emission reduction target, named the ‘Fit for 55′ package, which must be jointly approved by the European Parliament and the Council [5]. The package includes a set of changes to existing policies and new measures to reduce emissions, including target strengthening for member states, revision of the EU Emissions Trading System and Energy Taxation Directive, limitations with higher CO_2 emission standards for vehicles, new EU Forest Strategy, etc. [6]. The reduction in greenhouse gases should continuously drop to zero emissions by 2060–2070 if EU is going to take responsibility for meeting the <2 °C target agreed to in Paris [7].

In order to propagate the concept of low carbon and emission free, highlight the recent progress in energy research, and provide studies to communicate topics regarding sustainable development, the 16th Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conference was hold on 10–15 October 2021 in Dubrovnik, Croatia. A total of 675 oral presentations, including 13 special sessions, were presented by distinguished experts, scientists, and authors in the field of energy. Meanwhile, 223 participants participated in the conference in person, who also had the chance to meet, mingle, and share their new ideas and concepts. Furthermore, the Project Exchange Event was held via onsite conferencing, which received significant interest. As a result, a total of 17 projects were presented, and many attendees were interested in hearing about them.

Energies, which is an international, peer-reviewed open-access journal, has cooperated with the SDEWES series for many years [8]. Meanwhile, *Energies* provides researchers with an excellent stage in this Special Issue to present recent advances in technologies, methods, and economic analysis for sustainable development [9]. In this Special Issue, a total of 13 papers were selected for publication. Papers addressing topics related to sustainable development using different energy systems and dedicated to the advancement and dissemination of knowledge on methods, technologies, and economic strategies for improving the development of sustainability using natural resources were collected, reviewed, and classified into main research fields.

2. Application of Renewable Bioenergy

2.1. Waste to Wealth Techniques

Bio-energy is regarded as one of the most applicable candidates for the replacement of conventional fuels [10], indicating viable energy innovation for globally sustainable development. Chai et al. [11] reviewed the recent development of biomass waste-to-wealth conversion using the supercritical fluid extraction technique, which can transfer biomass waste to value-added products for commercialized applications, such as bio-oil [12], bio-gas [13], phenolics [14], biopesticides [15], etc.

Biomass is regarded as one of the most CO_2-neutral fuels, showing a significant contribution to green-house gas emission reduction by substituting fossil fuels [16]. Esteves et al. [17] proposed a multi-objective optimized methodology coupled with the support of the lifecycle assessment framework. Greenhouse gas emissions and energy balance were regarded as two lifecycle performance metrics. Results showed that soybean biodiesel has greater energy potential than biogas and bioethanol, which generated lowest greenhouse gas emissions per kilogram of biofuel. Mancusi et al. [18] studied a multiple interconnected fluidized bed system for the chemical looping combustion (CLC) of solid bio-fuels, aiming to recover CO_2. The hybrid energy from various renewable sources, such as photovoltaic panels and wind turbines, was considered to be collected in the CLC processes. It was noted that the electric energy conversion efficiency of the hybrid system could reach about 30%, a value that far exceeds the value evaluated for a similar power-to-methane-fed system. It was predicted that, compared to the production of methane, the synthesis of the methanol-producing process is much more effective with respect to the electric energy storage efficiency. Kamizela et al. [19] provided the biomass factory concept to establish a technological system, which consisted of sewage microfiltration, conditioning, and cellulose material sludge in a wastewater treatment plant. The lifecycle assessment (LCA) of a wastewater treatment plant showed that the net CO_2 emissions were reduced by 5.8 kg CO_2 per 1 t of wastewater. Meanwhile, pronounced benefits of changing the eutrophication potential by 1.7 to 2.0 kg of N_2O and 2.78 to 3.0 kg of PO_4 per 1 t of wastewater can be achieved. In developing countries, biomass is also generated from natural and domestic waste, transferring traditional, inefficient, and unsustainable methods to environmentally friendly, energy-saving, and low-carbon methods [20]. More sufficient and sustainable utilization of bioenergy may significantly lower pollutant emission levels [21]. Tesfamariam et al. [22] evaluated the nitrogen fertilizer value of biosolids from wastewater using post-treatment dewatering biosolid treatment technologies. The highest nitrogen release per unit ton of biosolid applied reached 24 kg for the activated technique, which was 6 kg higher than for the anaerobically digested biosolid technique. Hence, the selection of an appropriate biosolid treatment and dewatering technique is key to improving the fertilizer value of biosolids. Cavaignac et al. [23] carried out an environmental and techno-economic analysis of biogas upgrading processes using Aspen Plus. Acid gases such as CO_2 and H_2S could be removed from municipal solid wastes, and the upgrading process significantly increases the heat combustion value of the final product and simultaneously reduced air pollutant emissions. Results indicated that the diglycolamine-based upgrading route could generate a biomethane product with 91% methane, removing up to 99% of CO_2. Using LCA, a further reduction of 95% in CO_2 equivalent emissions was reached.

Woody biomass power plants were rapidly constructed all over the country after the feed-in tariff scheme began [24]. Tabata et al. [25] discussed the positive and negative impacts of using woody biomass on economic, environmental, and social systems and ecosystems. It was noted that the annual expenses may increase, which is a positive impact because of its contribution to the economy and employment in the region due to the increase in the production value. However, the influence on the local natural ecosystem showed a negative impact when the woody biomass was not appropriately utilized. Meanwhile, the wastewater treatment and post-treatment drying techniques also play a crucial role in the fertilizer value of biosolids [26]. Benić et al. [27] investigated the potential use of a novel direct driven electro-hydraulic system for articulated forestry tractors (skidders), considering the significantly high energy efficiencies of such systems with respect to the classical electro-hydraulic systems. The skidder studied in a work. It is a seven-ton skidder equipped with a double drum winch. A comprehensive analysis of the skidder rear plate mechanism was performed, and static force profiles of the hydraulic cylinders were achieved for the rear plate based on measurement data from the literature and the mechanism dynamics. Both the classical and the direct driven electro-hydraulic systems were experimentally verified for the purpose of a comparative analysis of their efficiency. Experimental analyses were carried out under laboratory conditions for different hydraulic cylinder loading scenarios, including an unloaded cylinder case and several cases of different cylinder payloads. The results were utilized to achieve insights regarding the potential advantages of the directly driven electro-hydraulic system from an energy efficiency point of view with respect to the use of traditional proportional hydraulic systems. In fact, according to these results, an estimation of the skidder fuel consumption and possible fuel savings over the entire life span of the vehicle for a realistic vehicle utilization scenario was performed. The main result is that fuel consumption can be reduced up to five times in the case of the direct driven hydraulic system, with a yearly fuel saving of 85.05 EUR. Thus, the proposed system reaches the break-even point (return-of-investment point) in 4.12 years if a price difference of 350 EUR between the classical and the proposed system is not exceeded.

In recent years, studies regarding the recovery of waste oils from biodiesel fuels hve increased in the literature. Plata et al. [28] examined the effect of the proprieties of cooking conditions on selected properties of biodiesel produced from palm-based waste cooking oils (WCOs). In particular, the proprieties considered to affect the biodiesel proprieties were the cooking temperature, time of use, and length of reuse. Data on the cooking conditions employed at each restaurant were obtained using a quick survey completed by the owners of the restaurants. Various WCOs obtained from several restaurants in Bucaramanga, Colombia were considered: (i) fried chicken restaurants (FCRs), (ii) fast food restaurants (FFRs), (iii) snack producers (SPs), and (iv) typical restaurants (TRs). The biodiesel yield, kinematic viscosity, calorific value, and cetane number were evaluated for the different restaurants where the oils were collected. The results show that the palm-based WCO showed better proprieties than the other WCOs, achieving up to a 95% improvement in the biodiesel yield. However, the biodiesel yield might have been reduced by changes in the cooking temperature and the length of reuse was affected by the kinematic viscosity. On the other hand, the calorific value was unchanged as long as the cooking condition was significantly changed. Compared to petrodiesel, the cetane number decreased when the use and reuse decreased. The proprieties were as follows: yield: 93.1 +/− 0.2%; kinematic viscosity: 5.0+/− 0.3 mm^2/s; calorific value: 39.9 +/− 0.1 MJ/kg; density: 919+/− 9 kg/m^3; and cetane number: 67.4 on average.

2.2. Hybrid Bio-Energy Systems

There is an increasing awareness of examining the aspects of biofuels and combined biomass and other renewable energy sources in relation to the process of the sustainability framework [29]. The utilization of hybrid bioenergy systems has been gaining attention as a comprehensive framework for diagnosing, optimizing, and improving comprehensive designs.

Sivri et al. [30] experimentally investigated the effect of fuel composition, hydrogen addition, and the swirl number on the combustion efficiency and emission characteristics of various biogas mixtures. Based on the gas composition, both the radial and axial temperature distribution of tested biogas mixtures varied significantly with the hydrogen addition. A non-monotonous dependence on the swirl number outside the flame region was found because of the modified flow characteristics. The CO_2 emissions were also non-monotonous dependent on the fuel composition. Samir et al. [31] presented a comprehensive assessment of two butanol production biorefineries, involving sensitivity, techno-economic, and exegetic factors. Aspen Plus software was applied to construct the biorefineries, revealing reasonable evaluations of the production capacity, biomass feed flow, net present value, and return on investment. Cirillo et al. [32] presented a numerical model to predict the performance of a fixed-bed micro-cogeneration biomass gasification system coupled with a spark-ignition internal combustion engine. The performance of the system was linked to the main gasifier and engine parameters. The global electrical error predicted by the model could be controlled within 0.5% while the prediction of the thermal efficiencies away from the measured values was reduced to be within 4.0%. The consistency of the multi-component thermal properties may significantly affect the system efficiency. Bietresato et al. [33] investigated the kinematic viscosity of fuel blends with diesel oil-biodiesel-bioethanol and its effect on engine performance. It was noted that the viscosity of the mixed bio-fuel progressively increased by 38% at 40 °C while the biodiesel percentage ranged from 0 to 100%. It was suggested that a preheater should be installed in the fuel-feed system. The preheater might obtain the same fuel viscosity of the blends as the pump diesel oil and that the bioethanol fluidizes the blends, reducing the viscosity by about 2% per percentage point of bioethanol in the blend. Safe handling and utilization of bioenergy to avoids risks such as fires and explosions has come into focus in recent years. Manic et al. [34] presented an innovative thought for assessing the ignition risk and provided a ranking of the ignition risk for biomass fuels. Their results provided relatively accurate, simple, and quick determination data necessary for the design and application of appropriate measures to reduce fire and explosion hazards related to the operation of biomass. In recent years, the CO_2 storage and CO_2-enhanced oil and gas recovery in shale reservoirs has received significant attention [35]. Jia et al. [36] proposed a methodology for analyzing variations in the shale gas permeability during the production process, considering the impact of pore size reduction, the adsorption layer, and non-Darcy flow components simultaneously. Results showed that the geo-mechanical effect significantly reduced the intrinsic permeability of shale gas. Due to a lack of studies on the CO_2 storage capacity in shale reservoirs under a wide range of pressure, the CO_2 flow behavior in shale reservoirs was investigated [37], illustrating an important impact on both the improvement in CO_2-related oil recovery and enhancement of gas recovery and carbon sequestration. Then, they [38] further measured the high-pressure CO_2 adsorption in low, middle, and upper Bakken shales. It was confirmed that the nuclear magnetic resonance is eligible for tracking the fluid movement before and after CO_2 exposure in shales, and the most important impact factor is the adsorption outweighing the molecular diffusion, which may determine the CO_2 injection rate. With the development of artificial intelligence techniques, bioenergy systems can be optimized automatically, revealing more effective progress based on existing experimental and numerical data [39].

David et al. [40] modeled the bio-fuel gasifier model using the inbuilt biogas power plant modules in HOMER software. An electric generator, through the syngas produced in a downdraft biomass gasification plant, was simulated while both technical and economic parameters were included. A case of isolated rural communities in Honduras and Zambia was studied. Results showed that the energy supply demand and energy distribute demand by the microgrid had a levelized cost of energy, which is lower than the scheme of extending the electric grid to the communities. Juan et al. [41] developed a multi-objective target-oriented robust Monte Carlo model to optimize a biomass co-firing network, integrating uncertainties in the biomass properties with investment and operations planning. Compared to the deterministic solution, the robust optimal network had a relatively insusceptible influence on the uncertainties. Bedoic et al. [42] developed a robust optimization model with the objective of minimizing the total costs. Linear programming, considering the market price of electricity, was coupled in a mathematical model, which was tested in a 1 MWel installed biogas power plant. The economic analysis showed that an improvement in the feedstock gate fee of 100 €/ton may result in a significant decrease in the production costs of renewable methane of 20–60%, showing significant economic viability. The robust model also indicated that the uncertainties related to electricity production from wind and photovoltaics amy increase the cost of gas production by 10–30%. Bartolucci et al. [43] presented a study regarding the data-driven optimal design of a combined heat and power (CHP) plant for a hospital building. The proposed methodology allows one to simultaneously optimize the economic and environmental performance of the considered CHP plant coupled with the anaerobic digestion (AD) process of spent coffee grounds using biogas for co-burning or completely substituting the fossil methane to fuel the CHP unit. The effects of integrating energy storage technologies, such as thermal energy storages and battery energy storage systems, were investigated. Optimization of the plant was performed using a bi-level optimization approach applied to a real application consisting of a large Italian user in Rome (Italy), the Tor Vergata Hospital. In fact, CHP power plants are often used for hospital users due to the significant and simultaneous thermal and electric energy demands. In particular, this hospital includes a 350 kW NaBr absorption solar cooling plant, 100 kW PV panel field, and a 2 MW CHP plant based on a reciprocating internal combustion engine (ICE) fueled by natural gas. Considering the historical data of the electric and thermal energy demand of the hospital, a clustering analysis was applied in order to identify specific load patterns representative of the annual load. These patterns were used as input data in the design procedure. A genetic algorithm coupled with mixed integer linear programming was used to optimize the size of the CHP plant and energy dispatch, respectively, with the aim of minimizing the carbon emissions and total costs and maximizing the primary energy savings. The results of this particular approach highlight that proper design of combined heat and power plants is useful for achieving a CO_2 emission reduction of about 10%, with economic savings of up to 40%, when the proposed CHP plant is compared with a system with the conventional separated production. Additional environmental benefits can be achieved by means of the integration of anaerobic digestion and energy storage, increasing the CO_2 savings up to 20%.

3. Component Enhancement in Renewable Systems

3.1. Heat Exchangers in Renewable Systems

It should be noted that the higher energy efficiency of renewable systems can achieve greater eco-sufficiency and energy conservation [44]. Due to the dramatically growing energy demands, sustainable development has become imperative, especially for industrial progress [45]. In this regard, the efficiency improvement in renewable systems has become a critical concern [46]. The application of heat exchangers (HXs) has a pronounced effect on energy saving and thermal energy integration [47].

The structural optimization, orientation arrangement, and change in the working conditions of HXs can effectively improve their thermal performance [48]. Holic et al. [49] investigated the application of a waste heat recovery unit for the recovery of waste heat through the Rankine cycle and organic Rankine cycle, which was installed between the exit of the engine and the exhaust cooling heat exchanger. A multi-objective thermo-economic optimization procedure was proposed and applied. For the case with exhaust gases of 1.77 kg/s at a temperature of 410 °C, the electrical efficiency could be improved by 2.97% and the investment payback period was reduced to 6.8 years. Tian et al. [50] proposed a shell-and-tube heat exchanger with a moving packed bed with elliptical tubes, which could significantly reduce the cavity zone and stagnation zone in conventional shell-and-tube HXs. The results showed that the heat transfer coefficient at the top and the bottom could be improved by an average of 42% and 53%. The heat transfer in the inside tube was increased by 5% to 29%. Meanwhile, the flexural capacity was simultaneously improved by 8% to 36% when the new HXs were applied. Lian et al. [51] proposed a hybrid printed circuit heat exchanger (PCHE) with a comprehensive flow channel design, which can significantly enahcne the thermal performance. In comparison to conventional PCHEs, the core volume could be reduced by 49% at the same thermal load, equivalent to a 145% improvement in the heat transfer rate per unit volume. Ma et al. [52] studied the local heat transfer performance of PCHEs under rolling conditions. It was reported that rolling might improve the heat transfer by 25% while jeopardizing the pressure drop by 75% using trans-critical natural gas. However, the maximum Nusselt number could be raised by 40% with a minor change in the pressure loss in the subcritical zone under the rolling condition. For natural gas flowing under pseudocritical conditions, the maximum Nusselt number could be improved by 15%. Zheng et al. [53] investigated the performance of a plate heat exchanger when dispersing 20-nm-diameter Fe_3O_4 spherical nanoparticles. It was indicated that the Nusselt number can be enhanced by an average of 21.8% when two magnets were vertically arranged side by side. Compared to the case without spherical nanoparticles, a pressure drop with a 10% reduction could be achieved.

Despite the improvement in the physical parameters, the application of artificial intelligence and topology modification to the new HX design and optimization has also shown a notable effect and good payback. Li et al. [54] deployed a network retrofit and constructed a network topology modification strategy for heat transfer enhancement of HXs. They proposed a target evaluation methodology, which considers the thermal efficiency, pressure drop, and level of heat transfer enhancement simultaneously. It was found that the best design of HX can achieve a significant improvement in the economic efficiency and energy savings. Moreover, fewer modifications based on the original existing heat exchangers were executed. In one case study, the energy saving rate was 10.6752 MW, displaying a 13.3% improvement in the heat transfer rate. Age is negatively correlated with HXs' performance and efficiency. Chin et al. [55] constructed a mixed integer linear programming (MILP) model to evaluate the economic performance and decide whether to upgrade the heat exchangers or purchase new heat exchangers. This method integrates the HX lifetime, reliability functions, investment, and maintenance to visualize the benefit of hybrid processes. The results showed the 20 years is the planning horizon. Then, Zirngast et al. [56] presented an modified method named mixed integer nonlinear programming (MINLP) synthesis to search for the best design variable parameters of a flexible heat exchanger network. The MINLP was based on a large number of databases with uncertain parameters, and it was eligible for simplifying the complicated searching problem, with the size variable remaining independent of the number of parameters. Results showed that the implementation of the synthesized MINLP in heat exchanger optimization could reduce the search time and improve the optimal result by 7.6%.

A multiscale approach can also be applied to HX design in heat recovery systems, e.g., district heating [57], photovoltaic systems [58], and combustion engines [59]. Moita et al. [60] addressed two heat recovery systems for two macro-applications: (i) cooling of a PV cell, where the subtracted thermal energy is used for desalination purposes; and (ii) the recovery of thermal energy from exhausted gases with the application of innovative heat pipes associated with the thermoelectric generator. The researchers presented experimental results, including temporal resolution, visualization, high-spatial thermography, and flow hydrodynamics. Both discussed recovery systems illustrate the potential of the application of two-phase flows. However, the instabilities should be accurately addressed for microscale applications. The most significant contribution was the proposal of comprehensive and innovative flow analysis to optimize the channel structures, displaying high-speed visualization with time-resolved thermography. The main results achieved from these experimental tests demonstrate that a significant improvement in the dissipated power could be achieved using the microchannel-based heat sink at the expense of controlled pumping power. In addition, compared to existing systems, promising results were achieved by the application of the proposed thermal control strategies. The high-efficiency operation of thermoelectric generators under highly fluctuating thermal loads could be explained as a high usability was reached due to the available exhaust heat.

3.2. Other Components for Renewable Applications

Renewable energy systems frequently operate in off-design conditions [61]. Generally, the application of volumetric-type machines and their capacity could overcome the concerns regarding time-varying fluid thermodynamic properties [62]. On the other hand, it is also crucial to consider the proper design and selection of expanders to successfully overcome unsteady operation.

Fatigati et al. [63] investigated scroll expanders as novel technology to be integrated into a small-scale power unit with an organic Rankine cycle (ORC). This technology, in the case of small applications, operates in off-design conditions. The authors proposed a novel system named a dual-intake-port (DIP), with an intake port added to the main one. Modification of the expander permeability increased the flowrate in the ORC system, and the off-design conditions were also significantly improved without increasing the inlet pressure of the expander. The authors assessed the feasibility of DIP technology, which demonstrated that the novel solution is eligible for other volumetric expanders. In this regard, a comprehensive numerical model was further proposed with experimental validation. GT-SUITETM software was applied for the scroll expander modeling, allowing mono-dimensional (1-D) and zero-dimensional(0-D) integrated analysis. The prediction errors of the mass flow rate and mechanical power could be controlled within 2.6% and 6.7%, respectively, which is regarded as a trustable prediction method for assessing the DIP feasibility. The position and geometry of the second port was optimized and a comparison with the baseline system was carried out and the singe-intake-port was assessed. It was reported that the introduction of the second port could provide an increase of 25% in the mechanical power and an increase of 37% in the mass flowrate when the optimized configuration was applied. With respect to the baseline machine, DIP technology produced an increase in the mechanical power of about 25%. As a result, the power was raise increased from 1131 to 1410 W with an unchanged pressure difference across the expander of 5.6 bar when the DIP technology was implemented. Meanwhile, the DIP scroll showed a higher efficiency than the DIP SVRE case, 50–60% vs. 40%.

On the other hand, the design of the header may affect the flow distribution and mixture uniformity in the core component [64]. Fadzil et al. [65] developed a novel centralized water reuse header. When two units of headers were applied, consumers were eligible for benefits of 50.9% in cost savings in freshwater and an 89.6% reduction in wastewater. Wołosz [66] presented the development of detailed energy analysis of an industrial nozzle. Due to the nonuniform distribution of the energy flux across multi-channels, the nozzle efficiency was analyzed. The OpenFOAM® toolbox with the finite volume method (FEM) was applied to determine the gas energy magnitude and flow parameters.

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