Advances in integration of energy, water and environment systems towards climate neutrality for sustainable development

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Abstract
The integration of energy, water and environment systems represents important opportunities for addressing the urgent imperative of climate neutrality. The 29 original papers in the virtual special issue of the 14th Conference on Sustainable Development of Energy, Water and Environment Systems exemplify multiple advances in integrated approaches. This editorial provides a review of recent scientific contributions in energy system integration, urban synergies in the energy transition, integration of energy and water systems as well as valorization of waste heat. Advances that relate to sustainable combustion, biomass, and managing emissions provide further perspectives. All seven themes contain new research directions in such areas as solar energy technologies, thermal energy storage, power-to-X technologies, district heating and cooling networks, wastewater treatment plants, water desalination, and salinity gradient technologies. Advanced optimization approaches, big data analytics for cogeneration, thermal management applications, pollution minimization, lignocellulosic biomass, catalysts for alternative fuels as well as carbon capture, storage and utilization are described among other scientific contributions. Across the world, the focus on integration is gaining prominence, especially with the European Union Strategy on Energy System Integration that recognizes the role of a coordinated approach for planning and operating the energy system as a whole. The research advances that are contained in this editorial will support the realization of a coherent approach on the path towards sustaining the life-support systems of the planet and thereby support sustainable development.

Keywords: Energy, water, environment, sustainable development, system integration, climate mitigation

1. Editorial introduction to the special issue of the 2019 SDEWES Conference

In a world that is on the verge of exceeding tipping points in the global climate [1], pathways for a more sustainable future require an immense shift towards solutions that are more coherent and systemic than the ones before. System transitions that are related to energy, urban infrastructure, industry, land and ecosystems represent the scale and scope of the transformation that is deemed vital for any chance of respecting the 1.5°C target [2]. In the context of feasible alternatives with rapid electrification based on renewable energy [3], directions for the future that focus on system integration provides a promising potential for effective mitigation pathways. Research directions in support of integration can effectively guide policies, strategies, and measures for better closing implementation gaps in curbing emissions [4].

Since the beginning of the 21st century, the Conferences on Sustainable Development of Energy, Water and Environment Systems (SDEWES) have encouraged new research directions towards integration and strengthened the knowledge base to advance new solutions for sustainability [5]. The SDEWES research community recognizes that one of the main issues of the coming decades is to improve efficiencies by integrating various energy systems, using excess from one, as resources in another in the correct moment. The vision that the integration of opportunities across electricity, heating, cooling, transport, water, waste, wastewater, buildings, industry, forestry, and agriculture systems will be pivotal for sustainable development defines the guiding principle of these research efforts. With this aim and

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continuing the series of regular and regional conferences that reach across the globe, the 14th SDEWES Conference to which the special issue of this editorial belongs was held in the home venue of Dubrovnik, Croatia during October 1-6, 2019. The Conference brought together 570 researchers from 55 countries around a scientific programme that contained 511 oral and 100 poster presentations, a record of 17 special sessions, 4 invited plenary lectures, and various panels and events, including perspectives on 100% renewable energy systems around the world with contributions from distinguished experts in the field. The stimulating environment enabled researchers to share key progress and discuss the state of the art, future research directions and priorities for integrating energy, water and environment systems.

The multi-disciplinary stock of knowledge that emanates from the SDEWES Conference series has led to more than 1,900 articles being reviewed and published in special issues of leading scientific journals to date, supporting researchers to increase their impact for a more sustainable future. The research directions that are put forth by the SDEWES community over the years have also had an influential role in bringing integration to the forefront of policy action as represented in the new European Union (EU) Strategy for Energy System Integration [6]. This Strategy aims to ensure that energy systems of the future are efficient, resilient, and secure towards climate neutrality. Such a strategic direction forms a significant pillar for establishing the European Climate Law for a climate-neutral continent by 2050 and realizing the European Green Deal with decoupling of growth from resource use as persistently upheld by SDEWES researchers. As in Europe, integration provides opportunities for energy systems around the world as rapid climate mitigation continues to be an urgent imperative for sustainable development.

The productive partnership with *Energy Conversion and Management* is sustained in this virtual special issue [7] that represents the seventh collection of research articles that are dedicated to the SDEWES Conference series. Research directions for integration have become ever more vital given the significant technological shift that remains necessary to protect the life-support systems of the planet in the context of the limited time ahead to curtail the growing impacts of climate change. This special issue as the ones before [8], [9], [10], [11], [12], [13] provides new research contributions that advance multiple opportunities for integration across energy, water and environment systems for the realization of the energy transition. Figure 1 puts forth the main themes that structure the review in this editorial with connections between the 29 articles in the special issue and other recent research contributions from the SDEWES community. In total, seven main themes take place within the scope of this editorial.

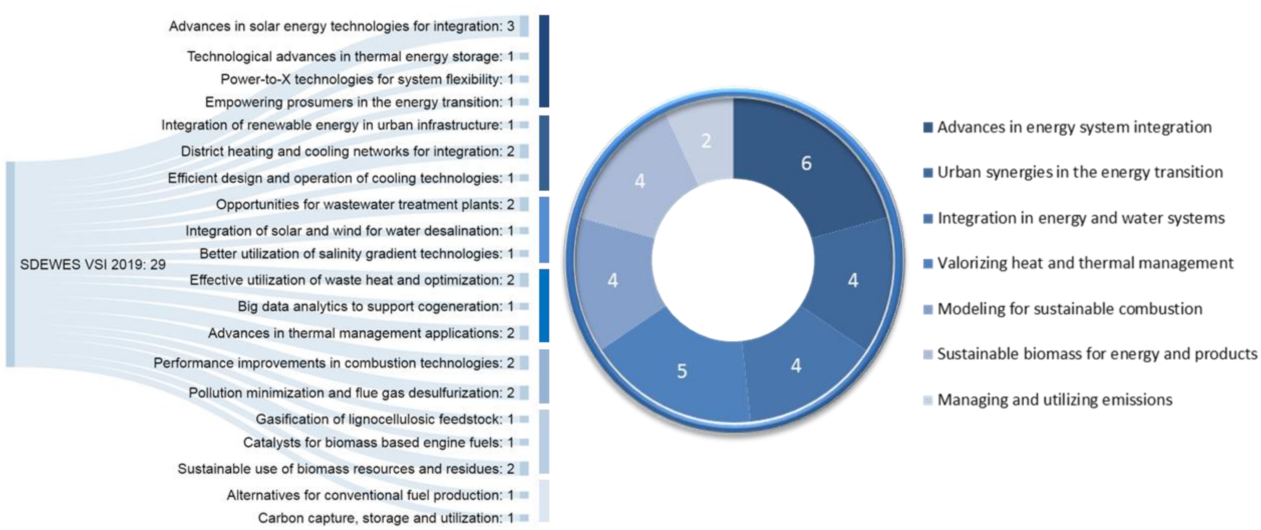

Figure 1. Distribution of research articles across the themes in the SDEWES 2019 special issue

2. Advances in energy system integration

SDEWES researchers have been pivotal in producing scientific contributions that have guided the design and implementation of integrated renewable energy systems. The scientific guidance that is provided by the SDEWES community has been instrumental in steering such policy directions as the EU Strategy for Energy System Integration that targets powering a climate-neutral economy [6]. The focus that is placed on energy system integration based on a coordinated approach for planning and operating the energy system in its entirety has been a pivotal tenet of the SDEWES research community. Realizing systemic integration is now all the more important to address the urgent need for accelerating climate mitigation.

The scientific community of SDEWES has advanced visions for energy system integration based on such pioneering studies as the RenewIslands method [14], the smart energy systems approach [15], and Heat Roadmap Europe [16]. These studies continue to open new research directions in support of realizing opportunities for energy system integration from islands to world regions. Among the most recent studies, Meschede et al. [17] analyzed 502 off-grid islands of various sizes in the Philippines to determine the solar and wind energy potentials for renewable islands with the integration of the power, transport, and water desalination sectors. In another recent study [18], a method was developed to quantify the potential of load shifting in important infrastructures of island energy systems. The results for demand response and sector coupling in the scope of the case study based on a touristic facility that has an important role in the Canary Islands indicated benefits for the entire island energy system. In the study of Bertheau [19], 649 islands without electrification in the Philippines were considered for 100% renewable energy systems, underlining ways in which renewables support sustainable development.

The emphasis on cross-sector approaches for coherent, smart energy systems requires flexibility to enable higher shares of renewable energy [20]. In this context, Seefried et al. [21] reviewed options that provide temporal flexibility to power grids with a high penetration of variable renewable energy sources. Short, medium and long term flexibility options based on the flexible generation of power plants, demand-side management across sectors, electricity storage, and power-to-X technologies were reviewed with an analysis of their potentials for two study regions in Germany. As other recent contributions from the SDEWES community, Moser et al. [22] determined possible shares of innovative electrical energy storage options for flexibility in scenarios with greater than 95% reduction in carbon dioxide (CO_2) emissions in Europe considering pumped hydro, underground hydrogen storage, batteries, and power-to-heat-power. Jimenez-Navarro et al. [23] analyzed the potential of coupling the heating and power sectors through combined heat and power (CHP) plants to find the possibility of covering 70% of heat demands in a low energy scenario for 2050. Pfeifer et al. [24] proved the feasibility of demand response technologies based on power-to-heat and vehicle-to-grid as well as flexible operation of CHP plants in integrating up to 2450 MW of solar PV into a future Croatian energy system in 2030.

Energy system actors that advance their ability for integration in the energy transition can capture greater benefits relative to those that delay action. Pfeifer et al. [25] compared scenarios with different levels of ambition in increasing renewable energy penetration in connected power markets in the year 2030. The results indicated that more ambitious zones benefit at the expense of less ambitious zones while providing lower marginal cost of electrical energy by 70%. New tools and scenarios as developed by SDEWES researchers support gaining time for action. Taseska-Gjorgievska et al. [26] emphasized the advantages of combining multiple tools to support renewable energy scenarios for Macedonia, including those to determine the most appropriate locations within the transmission network. Pavičević et al. [27] developed scenarios up to the year 2030 for six countries in the Western Balkan region with an extra renewable energy share of 28.5% based on PV, wind energy, biomass, and hydropower. Based on a renewed interest in geothermal energy due to the new Renewable Energy Directive, Macenić et al. [28] constructed a novel gradient map for a part of the Pannonian Basin based on data from 154 wells.

Smarter grid infrastructure, incentives, data sharing, and public acceptance are other necessary aspects to support the energy transition in Europe and beyond. As recent contributions from SDEWES researchers, Mabrouk et al. [29] investigated the energy, cost, and emission savings of a PV-wind system with battery energy storage that is managed under market and system led algorithms. Saracevic et al. [30] compared scenarios for flexible power generation in a biogas plant with partial participation in the electricity spot market to find the need for a demand-oriented premium for power generation. Mauleón [31] simulated roadmap pathways to find that policies that aim only at minimizing cost lead to delayed renewable energy investments while increased target values for investment can shorten time horizons and accelerate climate mitigation. Ribó-Pérez et al. [32] determined a hybrid method also involving Analytic Network Process to rank options for designing a renewable energy microgrid in a rural community in Honduras to find preferences for PV and wind with biomass gasification as a backup.

2.1. Advances in solar energy technologies for integration

Within the context of energy system integration, SDEWES researchers have provided significant contributions to advancing integrated approaches for the utilization of solar energy that is one of the drivers of the energy transition. Among recent studies, Roselli et al. [33] developed energy indexes to compare the results of dynamic simulations for solar PV integrated ground source heat pumps and battery energy storage systems in satisfying heating, cooling, and electric loads. In other studies [34], a renewable trigeneration system that involves evacuated solar collectors, a geothermal well, biomass heater, an absorption chiller, organic Rankine cycle (ORC), and lithium-ion energy storage was analyzed to find primary energy savings of 94.5% and CO_2 emission savings of 97.4% for a case study. Recently, the integration of solar thermal energy into production systems was reviewed by Anastasovski et al. [35] based on such approaches as pinch technology, mathematical modeling, and other optimization tools.

As options for concentrated solar power, Mazzoni et al. [36] developed a tool for simulating plants up to 35 kW_e with micro gas turbines that are not as widely used as Stirling engines. The tool provided promising results for the market attractiveness of a small scale system with a net power output of 6.5 kW_e. Other SDEWES researchers investigated the integration of solar energy in power plants based on parabolic trough and linear Fresnel collectors. In Gambini and Vellini et al. [37], the contribution of such solar energy technology to electricity generation in hybrid power plants was determined with methods that focus on real-time operations, which can also be used to determine compliance with renewable energy targets. In another study, a 100 MW power plant with a solar fraction of 2% based on parabolic trough solar collectors was analyzed based on its impact on increasing electrical efficiency [38].

Photovoltaic thermal (PVT) panels provide additional means of increasing the utilization of solar energy although their performance under real operating conditions still requires additional analytical support. In previous studies that were recently shared by SDEWES researchers, Herrando et al. [39] compared combined systems based on PVT panels with either PV systems for power or evacuated tube collectors for thermal energy. The former was found to save 1.4 times more CO_2 emissions than separate solar energy systems considering the real demands of a university campus in Bari. In Barone et al. [40], an innovative and low-cost PVT prototype that supplies heat to a heat pump and electricity for partial use on-site was analyzed to find primary energy savings between 52% and 80% in 8 different weather zones in Europe with a simple payback time that ranges from 3.2 to 4.8 years. In other studies [41], building-integrated PVT systems were compared through a new dynamic simulation tool that accounts for both energy savings from electricity generation as well as domestic hot water and warm air provision.

In this special issue, El Fouas et al. [42] develop a dynamic numerical model for PVT plants that consider multiple parameters that are important for the operational environment. The model is validated based on the comparison of the simulated results with experimental data from a pilot PVT plant at the campus of the University of Catania. The numerical model takes into account interactions between the front glass, PV cells, tedlar, absorbers, thermal fluid, and the water storage tank while providing inlet and outlet temperatures of the panel, the storage tank, surface temperature of the PV cells, and the yield. The pilot system provides about 430 W of power and 690 W of thermal production that corresponds to efficiencies of about 14.7% and 21.7% under a solar irradiance of about 1000 W/m^2. The temperature of the thermal production is about 35°C that would be wasted in conventional PV plants. The coefficient of determination between the numerically modeled and experimental measurements is found to be 0.99. The study opens important possibilities to monitor the performance of PVT systems and to detect any deviations in the operative conditions instantaneously as well as to plan for the matching of the thermal output with thermal demands in the vicinity, including for desalination and cooling demands.

The exuberant reduction in the cost of solar modules in recent years is driven by technological advances that are still ongoing. The advances that SDEWES researchers have provided are also significant, including the continuation of such efforts in this special issue. As another contribution in this special issue, Ocłoń et al. [43] compare sun-tracking and stationary solar panels with and without cooling to reduce the temperature of the panels and increase conversion efficiency. The research work addresses a gap in the literature for active cooling not only for stationary but also for sun-tracking PVT systems. The experimental analyses of both systems are conducted at the Cracow University of Technology under low solar irradiation. A numerical model for cooled panels that is validated with the results is developed to optimize the number of cooling segments. In the context of the experiments, the sun-tracked system provides higher conversion efficiencies than the stationary system by as much as 6.5%, all else equal, and exclusive of electricity use. Moreover, the improved cooling system that is activated with an advanced control system once the temperature of the panel exceeds 25°C improves the efficiency of the sun-tracking system by an additional 1%. The cooling performance is optimized when the number of cooling segments is increased to 6 segments with 12 cooling tubes that provide a temperature drop of 8°C and a more uniform temperature distribution in the cooled panels. The results of the study also quantify the amount of low-temperature heat that is obtained for seasonal heat storage that indicates the benefits of the sun-tracking cooled panels beyond direct increases in conversion efficiency.

Moreover, renewable energy driven cooling technologies are rising in importance as humanity as aggressively surpassed the 1°C average mean temperature increase above pre-industrial levels across the world with summer months reaching new temperature records year after year. While conventional cooling systems are mainly based on electricity that is not entirely driven by renewable energy sources so far, solar cooling technologies can provide for thermal comfort without contributing to additional CO_2 emissions when satisfying cooling demands. In some of the recent research advances of SDEWES researchers, Palomba et al. [44] developed an advanced solar cooling system, the performance of which was compared based on cooling power and energy savings in the context of Berlin, Athens, and Riyadh.

In this special issue, the review of Alahmer and Ajib [45] compares the technological advances in solar cooling technologies across thermally driven absorption or adsorption chiller systems, desiccant cooling systems, as well as flat plate, evacuated tube, and compound parabolic solar collectors. The role of low-temperature energy sources, particularly in desiccant cooling systems, is discussed along with other relevant comparison criteria. The approaches that have been used to optimize solar cooling technologies and their configuration are compared across particle swarm optimization, genetic algorithm, artificial neural network, integrated optimization approaches, and statistical as well as control strategy approaches. Certain challenges for the use of solar cooling in the industry are identified, including lack of international standards while 1350 solar cooling systems are already installed around the world, including a 500 kW solar cooling plant in Australia. Important opportunities in the research area of solar cooling technologies are found to relate to the improved performance of heat exchangers, the use of phase change materials (PCM), the development of hybrid systems, and the optimization of all auxiliary segments for high efficiency as well as continuous monitoring. The findings of the review provide perspectives that will be useful in allowing solar cooling technologies to gain a better lead over conventional cooling technologies with their various levels of continued impacts on global warming.

Beyond solar cooling technologies for meeting direct cooling demands, Calise et al. [46] had investigated a solar-assisted solution for a triple-pressure combined cycle power plant using a solar cooling system with an evacuated tube solar collector and an absorption chiller. The results were found to provide an effective increase in daily power production by up to 5.5% for an analyzed case in Almería, Spain.

2.2. Technological advances in thermal energy storage

Advances in thermal energy storage, including from solar energy sources, represent another area of research that is relevant for supporting advances in energy system integration. Among recent studies by SDEWES researchers, Rosato et al. [47] analyzed a solar energy-based district heating system with different configurations involving PVT panels and solar thermal collectors as well as seasonal borehole thermal energy storage. Other research directions in the SDEWES community have focused on the integration of solar thermal systems with latent heat storage based on PCM slurries. In Serale et al. [48], an algorithm for model predictive control was developed to improve such an integration to provide up to 31.8% of energy savings when optimized with a slacking variable while lowering unmet energy demand. Buscemi et al. [49] investigated the industrial scale integration of linear Fresnel solar collectors and concrete thermal energy storage as a solar energy-based process heating system for a pasta factory in Sicily, Italy that can reach an annual solar contribution of about 40% of the thermal energy demand.

The contributions of SDEWES researchers further extend to the use of PCM for high-grade thermal storage of cold energy. In the present special issue, Khor et al. [50] improve the storage capacity, charge, and discharge times as well as the charge, discharge, and cyclic efficiencies of such tanks based on the use of granular materials to fill the void spaces that are left in packed beds with macro-encapsulated PCM. Four different types of granular materials are analyzed based on quartzite pebbles, particles of alumina or aluminum, and micro-encapsulated n-decane to reduce the void fraction to as low as 0.30. The analysis is conducted on three kinds of macro-encapsulated PCM packed beds, namely an in-house and two commercial types. The trend of increases in the charge and discharge times as well as their efficiencies when compared to cases without the use of granular materials is similar across all three of the packed beds. The use of alumina particles provides the best result for improving the storage capacity while micro-encapsulated n-decane provides the best result for improving the overall cyclic efficiency up to 11.2% in the in-house and between 7.1% and 3.7% in the commercial options. Parametric analyses are used to determine that the use of alumina particles or micro-encapsulated n-decane can maintain cyclic efficiencies even when the encapsulation sizes of the PCM are increased by 60% to reduce cost. An increase in the heat transfer fluid flow rate at the inlet of the tank is also found to lead to a decrease in cyclic efficiency, all of which define options for maintaining or improving the performance of PCM thermal energy storage and extend the focus of analysis from packing density to energy performance.

Beyond thermal energy storage, other leading studies have supported electrical energy storage technologies. Nam et al. [51] extended the level of scientific understanding for the aging, state of charge, and cellular variations of Li-ion battery packs. The results, including those from Monte Carlo simulations, enabled new options for improving the design of battery packs. Boyle et al. [52] developed a fuzzy logic controller for large-scale battery storage systems that are integrated to grids with high penetration of renewable energy to ensure that state of charge is managed to remain at nominal levels.

2.3. Power-to-X technologies for system flexibility

Storage technologies from grid-scale batteries to electroyzers as well as demand response options across sectors, particularly power-to-heat, are vital in enabling energy system integration. Such storage technologies or demand response options constitute an important strategy alongside the electrification of end-use sectors that requires more intermittent renewable energy sources. Among the most recent findings, Steindl et al. [53] developed a k-nearest neighbor based regression model to support control strategies to enable demand response opportunities in energy flexible buildings. Large-scale storage of electric energy is also proving to be critical as the energy system continues to progress towards higher shares of renewable energy. Among recent advances, a calcium-looping process for the large-scale storage of PV generated electricity for dispatchability was put forth in Fernández et al. [54]. The process involved the use of abundant materials that are cheaper than other thermochemical energy storage options while the electric-to-electric efficiency was currently capable of reaching about 57.1%.

Power-to-X (P2X) technologies offer a wide range of opportunities to integrate variable renewable energy sources into useful forms that are demanded at the exact moment or later use. Among P2X technologies, power-to-gas (P2G) technologies offer the benefit of allowing renewable power to be converted into gas as a way of integrating the power and gas grids. P2G systems received attention from SDEWES researchers due to their role in increasing flexibility in an energy system with high penetration of renewable energy. In recent studies, Ancona et al. [55] had analyzed the innovative integration of a co-electrolyzer with a methanation section with an energy efficiency of 85% and exergy efficiency of 79%. Castellani et al. [56] also determined the footprints of using the Haber-Bosch process and Sabatier reaction to convert nitrogen and CO_2 in flue gas into synthetic ammonia and methane using green hydrogen. The total carbon footprint when using excess electricity from renewable energy was found to be about 0.8 $kgCO_2$ per kg of treated flue gas. Chisalita et al. [57] used life cycle assessment to compare the main processes as well as upstream and downstream processes for ammonia synthesis with a focus on green production routes in the hydrogen supply chain. Qian et al. [58] compared the performance of packed beds with random and grille-sphere composite packing for thermochemical energy storage based on methane steam reforming to find a higher conversion rate of the latter by about 2.7%.

In this special issue, Ancona et al. [59] analyze a P2G system with high-temperature co-electrolysis based on a solid oxide fuel cell and an advanced experimental methanator at high and low temperatures to produce rough quality synthetic natural gas with additional conditioning. The performance of the system is analyzed within ± 50% of the design inlet power as the off-design range of operation when coupled with a wind generator. Four different configurations are based on a P2G system that operates at ambient pressure or as a pressurized system with a solid oxide fuel cell at 600°C or 850°C, a high-temperature methanator at 450°C or 600°C, and a low-temperature methanator at 200°C. The P2G system that has the same temperature value of 600°C across the fuel cell and the high-temperature methanator does not require the use of a heat exchanger. The utilization efficiency across the different configurations ranges from 55.1% to 59.0% while the synthetic natural gas production ranges between 188 ton per year to 216 tons per year and methane (CH_4) production of about 180 tons per year. The produced synthetic natural gas is found to be suitable for displacing the use of conventional natural gas and represents the storage of renewable energy in a transportable form that can be exploited in existing infrastructure. This research work that provides new results for P2G systems also indicates that the economic performance of such systems is dependent on the investment costs as well as incentives.

2.4. Empowering prosumers in the energy transition

Empowered prosumers in more integrated energy systems who are engaged in the exchange of thermal and electrical energy in districts and proactive measures in energy communities are one of the changes that are taking place in the context of the energy transition. Such multi-directionality in energy systems is also disrupting the rigidities of the existing energy system towards greater energy system integration. Research advances that are put forth by SDEWES researchers have been supporting these changes by contributing to leading findings for demand response, business models, and new incentive schemes.

In aspects of business models that support the energy transition, Bhandari et al. [60] investigated collaborative consumption and community ownership models for solar PV based rural electrification in Niger. These local models were found to provide for about an 80% reduction in monthly expenses that increased the willingness to pay by a factor of about 4.7. Ugulu and Aigbavboa [61] analyzed the willingness of urban citizens to become energy producers based on PV in the rapidly growing megacity of Lagos, Nigeria to find an above average willingness, especially under public support. The solar energy revolution is also empowering citizens and communities around the world by distributing the ability to generate electricity beyond central power plants. In this context, microgrids with high shares of renewable energy were optimized from the perspective of connections to the electricity market. Markov et al. [62] had found that connections to power lines with moderate distances as well as upgrades provide favorable reductions in the total cost of a multi-energy microgrid for an ecotourism purpose.

Unquestionably, the paradigm shift that is taking place due to the empowerment of energy actors is an essential dynamic within the energy transition. At the same time, this dynamic is often conceptualized as interactions between the prosumers and the main central grid rather than among prosumers. In this special issue, Fichera et al. [63] provide a prosumers-centered focus and develop an agent-based model to determine the interactions for a given urban area when prosumers follow pre-defined rules for exchanging electricity. Hourly-based simulations are run for an urban area with 350 buildings in a municipality in Sicily, Italy. The agent-based model considers the distribution potential for each building where a distribution potential less than zero represents electricity received from another prosumer or the main grid and a distribution potential greater than zero represent outgoing electricity to other nodes in the urban area or the main grid. Two scenarios are determined for the suitable buildings in the urban area with the first scenario focusing on the installation of rooftop PV panels while the second scenario has micro-CHP installations that operate in heat-led mode. Priority is given to self-consumption at each node considering the electricity demand of each building across the mixed urban development, the electricity production under the scenarios, the utilization rate, and the distance between the buildings. The emissions that are avoided when compared to traditional supply from the main grid increase in the scenarios as the simulated distances increase from 50 meters to 200 meters between the prosumers due to greater opportunities for exchanging electricity in both a typical winter and summer day. The results of the research work are useful for underlining the role of prosumers in the energy system based on interactions to maximize the utilization of the generated electricity, which avoids electricity that is not self-consumed or locally distributed among agents and reduces the supply from the main grid.

3. Urban synergies in the energy transition

Energy system integration requires coordination and alignment between scales, including the local level in support of 100% renewable energy scenarios. At the local level, the density and diversity of sectors in urban areas represent valuable opportunities for advancing energy system integration by capturing synergies across sectors. Among recent contributions of SDEWES researchers, Thellufsen et al. [64] developed a method to guide cities to smart energy systems in the context of 100% renewable energy systems at the national and regional levels with a case study for the municipality of Aalborg in Denmark. The local smart energy system involved flexibility options based on heat pumps and district heating as well as smart charging. Leveraging heat densities, Möller et al. [65] developed heat supply strategies for 50,000 districts across 14 member states in the EU based on the integration of excess heat and the low enthalpy renewable energy sources of geothermal and solar energy in district heating systems. As a composite indicator, Kılkış [66] developed the SDEWES Index to benchmark urban systems based on performances related to energy, water and environment systems with applications to European cities [67], [68] and cities around the world [69], [70]. Based on benchmarking results for 120 cities, urban systems with greater levels of integration provided better rankings while cross-sectoral scenarios that utilized the local waste heat and biowaste potentials were compared as an outlook for the future [71].

Targets for nearly zero-energy and positive energy districts can be used as one of the planning tools in support of integration opportunities at the urban level. Such approaches have received strong support from the SDEWES research community with connections between energy and urban planning. Among these studies, Aste et al. [72] analyzed a district in Milan that targets being a nearly zero-energy district based on the integration of a small scale biomass CHP, ground source heat pumps, and roof-top PV panels in low energy buildings. Moreover, the target of net-zero exergy districts (NZEXD) was introduced within the SDEWES community with a focus on lowering the annual exergy consumption and increasing on-site renewable exergy utilization [73]. The target was applied to the Östra Sala backe district in Uppsala, Sweden with a phased approach in support of an exergy transition [74] and a focus on urban metabolism [75]. More recently, Kılkış and Kılkış [76] developed an algorithm to guide urban areas in reaching the NZEXD target while considering urban density and building materials to avoid carbon lock-in. Scenarios for a district in the province of Ankara, Turkey indicated the possibility of reducing the overall CO_2 emissions by 88% in 30 years. Ferrari et al. [77] reviewed 17 tools that are available for supporting energy planning in urban areas, including tools with and without spatial representation.

Other research directions for the urban context indicate that local energy generation can support new ways of load sharing between buildings with multiple options for interaction. The recent study of Marrasso et al. [78] analyzed a micro-CHP system that satisfies the energy loads of two separate buildings in Vitoria Gastéiz, Spain through load sharing. The results showed that the micro-CHP system can enable about a 35% savings in CO_2 emissions when compared to separate production with a payback period of 3.2 years under different incentive schemes. Tian and You [79] developed an optimization approach that includes the levelized cost of heat for supporting carbon-neutral energy systems. The approach was used to compare scenarios with biomass heating, geothermal energy for heating and ORC as well as lake-source cooling for the energy demands of the campus of Cornell University. Roselli et al. [80] analyzed a renewable energy system with PV and heat pump coupling with and without energy storage for an office building in Naples, Italy to find up to 93% savings in primary energy and emissions.

Advances in energy system integration are necessary to support the decarbonization of sectors that represent relatively greater challenges in so doing, including urban transport. Among recent studies, Bellocchi et al. [81] optimized flexibility options for high shares of intermittent renewable energy sources in the Italian system based on electric vehicle and heat pump penetration that supports electrification in both sectors. Buonomano et al. [82] dynamically simulated the integration of electric vehicles and buildings with solar energy systems to find primary energy savings of 57.7% in a case study for buildings in an Italian city. In addition to solar applications in buildings, Attia et al. [83] developed a solar energy supported electric vehicle prototype for additional power to charge the battery. Cipek et al.

[84] recently developed an algorithm with cascade optimization for improving the performance of hybrid electric powertrains based on different operating regimes and energy management options. Ajanovic and Haas [85] determined the sensitivity of life cycle assessment results for hybrid and battery electric vehicles based on the electricity mix, the total distance traveled, and embedded emissions.

Among such advances, the consideration of socio-technological interactions is essential for optimizing policy choices. In this context, Thomassen et al. [86] provided a review of approaches for integrating learning effects to assess technologies with a future-oriented outlook from renewable energy technologies to power-to-gas, desalination, urban low-carbon measures, and electric vehicles. The review identified the needs for including learning effects at various levels from components to end products as well as combining a view of learning effects across economic cost, technological efficiency, and environmental impacts. In another study, developments in the requirements of grid codes and market mechanisms are deemed to be necessary toward 100% renewable energy targets [87]. Social aspects are also at significant levels of interplay in the urban context. In Brandoni et al. [88], polygeneration options based on PV, heat pumps, and thermal energy storage were analyzed for households with elderly inhabitants in Northern Ireland to satisfy needs for thermal comfort while providing for about a 26% savings in CO_2 emissions and 80% lower energy bill. Lekavičius et al. [89] focused on the distributional impacts of investment subsidies with a concern for inequality and energy poverty issues with a case study on subsidies for residential energy technologies in Lithuania.

The use of green infrastructure in combination with the integration of renewable energy in the urban context provides other promising opportunities. In De Masi et al. [90], suitable configurations of a living wall with different orientations, insulation, and types of plants in the green layer were compared for reducing summer and winter energy building loads while improving thermal comfort and alleviating air pollution. In addition, the integration of renewable energy in urban areas can be accompanied by more efficient street lighting infrastructure, including those as proposed in Beccali et al. [91] in which an energy savings of 84% was found based on a phased retrofit in pilot areas on a university campus.

3.1. Integration of renewable energy in urban infrastructure

The integration of renewable energy sources into urban infrastructure represents an important opportunity for climate mitigation, including solar energy and heat pump coupling. Such opportunities support the energy transition since renewable energy integration in urban areas displaces the use of natural gas in boilers when used for space heating purposes. As related contributions to the literature from SDEWES researchers, Visa et al. [92] analyzed the integration of a novel solar thermal facade in research infrastructure in Brasov, Romania. Takruri et al. [93] developed a support vector machines model to determine the optimal operation points of PV panels, including in urban settings. The integration of PV and wind technologies and heat pumps at the level of new and existing buildings to meet the nearly zero energy target was also analyzed to find benefits for the stability of renewable power production [94]. Additionally, complete avoidance of CO_2 emissions with payback of 5.2 years in a case study in Pantelleria Island was found with applicability to settlements as well as touristic districts.

In the present special issue, Calise et al. [95] focus on innovative system designs at the district level that are modeled on a daily, monthly, and yearly basis. The innovative system designs involve solar PV fields, evacuated tube collectors, electric air-to-air heat pumps, and air-to-water CO_2 heat pumps to partially cover the electrical energy, space heating, and cooling as well as domestic hot water needs of the district. The system designs are subjected to thermoeconomic as well as parametric and sensitivity analyses with different PV field areas and prices for the electrical energy purchased and sold to the grid as well as for natural gas. The approach is applied to residential district areas with 50 buildings each in the Italian cities of Naples and Turin that have a primary energy usage of 17.33 GWh and 23.61 GWh per year, respectively, and annual operating costs of at least 1.5 million €. Considering the aim of minimizing surplus power and maximizing the self-consumption of renewable power, the renewable energy systems are found to result in primary energy savings of between 58% and 76% in the two district areas with a payback period of 5.1 years in Naples and 10.6 years in Turin. The PV plant covers between 29% and 32% of the total electric energy demand with at least 44% of self-consumption within the district and the evacuated solar collectors cover between 39% and 47% of the domestic hot water demands in the two district areas. The results open opportunities to be integrated with urban planning, including the area for the PV plant, as well as coupling with other renewable energy sources, including wind energy.

3.2. District heating and cooling networks for integration

District heating and cooling (DHC) networks provide strategic opportunities for increasing the share of renewable energy in urban areas as well as integrating sources of waste heat. These assets can accelerate decarbonization and allow for sector coupling as urban areas strengthen their support of energy system integration. In this respect, research directions for DHC networks have consistently received significant contributions from the SDEWES community, including those for optimizing such networks and their role in renewable energy systems. In addition, the concept of fourth generation district heating (4GDH) as pioneered in Lund et al. [96] was initiated with numerous studies thereafter.

Among the most recent studies, Dorotić et al. [97] developed a novel method to optimize district heating systems based on the multiple objectives of minimized discounted cost, CO_2 emissions, and exergy destruction. Solutions were obtained in a Pareto surface to support decision-making, including those solutions for phasing-out heat only boilers to lower the exergy destruction. In addition, Doračić et al. [98] compared five scenarios according to levelized cost of heat, including district heating with supply temperatures between 55°C and 85°C and excess heat with temperatures between 35°C and 85°C. Kazagic et al. [99] analyzed Visoko municipality in Bosnia and Herzegovina to determine the integration of renewable energy and waste heat in modular DHC systems to meet increasing urban energy loads. Pieper et al. [100] compared the seasonal coefficient of performance of ground source, seawater, and air-based heat pumps for district heating systems to suggest that a combination of multiple heat sources may provide up to 11% higher performance than single sources in the context of Copenhagen, Denmark. Djørup et al. [101] explored the optimal level of saving heat in buildings and proposed a variable local tariff for district heating that can support making progress to lower temperatures in 4GDH systems.

As other contributions, Askeland et al. [102] analyzed renewable energy-based district heating scenarios to replace individual electric heating in Norway. The results underlined the possibility of freeing loads on hydropower resources and exporting up to 19.66 TWh of electrical energy per year to Europe in support of energy system flexibility. Aunedi et al. [103] developed a model to optimize the levelized cost of supply side options for district heating, including options for increasing flexibility. The results indicated that thermal energy storage can be increased by about 50-66% in high renewable energy penetration scenarios with a focus on power-to-heat from excess electricity generation, which has system-wide benefits. The waste heat market is also developing, including in the concept of “open” district heating in Stockholm where the hourly feed-in incentive is shared a day ahead. Similar options inspired SDEWES researchers to develop new policy tools, including the Heat Merit Order in Moser et al. [104]. Among other recent studies in this area, Laine et al. [105] compared the emission impacts of utilizing data center waste heat in district heating networks with a case study in Finland to find that reductions in all three scopes are possible when utilizing half of the waste heat with changes in electricity production.

In an effort of promoting a rational allocation of energy resources and freeing biomass resources, Østergaard et al. [106] analyzed the conversion of biomass-based district heating systems into heat pump based systems with the use of local wind energy using the island of Samsø as a case study. Nguyen and Gustavsson [107] compared cost-optimal district heating systems as well as coproduced electricity versus biofuels for transport to analyze the role of bioenergy in future energy systems. Bozhikaliev et al. [108] analyzed a bioenergy based district heating system for Kichevo, Macedonia using sustainable forest residues to find 40% cost savings compared to a fossil fuel-based district heating system.

In this special issue, Barone et al. [109] develop an original dynamic simulation model for determining the system characteristics of new DHC networks as well as those that may provide options for upgrading. The model considers the entire system from the supply to the demand sides based on technical variables that relate to the cogeneration plant, the pipeline network, substations, heating/cooling profiles, and others. The model considers different objective functions for maximizing primary energy savings, the avoided CO_2 emissions, or reducing the system payback in comparison to a reference system without a DHC network. The number of users is optimized according to these objective functions and the urban area is analyzed to find the most convenient locations considering energy sources as well as the height and proximity of the buildings. The pipeline network is modeled according to the number of users and the urban area while giving priority to higher rise buildings with greater urban density. The model is applied to the S. Giovanni – Barra neighborhood in Naples that has a power station with cogeneration capacity while currently producing only electricity with an efficiency of 55% and releasing 100°C to the atmosphere due to the lack of a district heating network. Buildings that are nearby to this power plant use natural gas in boilers, a situation that can be improved through a new district heating network. For this reason, the model is used to determine a district heating layout considering such variables as the number of users, flow and return temperatures, working fluid flow rate, and pipeline diameters. Based on the proposed layout that currently involves a third-generation district heating network considering the existing building infrastructure, 19.9 GWh of heat is supplied to users in the urban area with 11.7 GWh of primary energy savings and 16.1 ktonne of avoided CO_2 emissions on an annual basis. The model is similarly applicable to fourth and fifth generation DHC networks that provide opportunities for urban areas in their efforts to reach climate neutrality.

As put forth in this study, the planning of DHC network characteristics represents multiple opportunities for optimizing the performance of such systems. Among the recent studies of SDEWES researchers, Dominković and Krajačić [110] determined the optimal district cooling share within the total urban cooling energy demand of Singapore in the context of broader scenarios that considered PV panels, grid storage, electric vehicles, and hydrogen storage. Dominković et al. [111] also modeled the urban energy system of Singapore with interactions among the power, cooling, gas, mobility, and desalination sectors with large scale storage options to find that it is feasible to lower CO_2 emissions by about 68% by the year 2030. The design of grid topology for harnessing and sharing waste heat in fifth generation DHC networks was also recently optimized. In von Rhein et al. [112], topologies of radial, ring, and meshed grids were compared for the participation of prosumers as consumers and producers of thermal energy to find that the radial grid provides the most feasible solution under conditions with low load diversity.

As extensions of ongoing contributions in the field of DHC research, in the present special issue, Allen et al. [113] compare the integration of two building technologies with connection to a district thermal energy network that replaces split systems without district level connection. The analysis considers air-based or radiant heating and cooling systems in buildings, the optimization of the network typology, and the total life cycle cost benefits over a time horizon of 20 years considering projected prices of CO_2 emissions. A building cluster with three office buildings, a retail building, and a central plant serving a district thermal network in the climatic context of Golden, Colorado is compared based on 212 different connection possibilities. In comparison to a conventional district, buildings that are equipped with low-exergy radiant heating and cooling systems with connections to the district thermal energy network are found to provide at least 49% savings based on total site energy intensity and 51% savings based on total source energy intensity. The results are useful for distinguishing energy savings when more efficient building technologies are coupled with district level solutions. Districts with a greater diversity of thermal energy loads can also enable the bidirectional exchange of thermal energy based on the activities of prosumers in fifth generation DHC networks. Such opportunities are evaluated to be valuable for substantially increasing deeper energy savings and utilizing waste heat in the future.

3.3. Efficient design and operation of cooling technologies

Energy system design options, including parallel and series configurations and storage options, have received continued interest within the SDEWES research community. Osman and Jankovich [114] developed a unified approach to maximize the efficiency and minimize the electricity demand of the system architecture of cooling plants, including the chiller selection. Kılkış [115] compared series and parallel heat pump configurations with and without the coupling of heat recovery ventilation units from an exergy point of view. Al Quabeh et al. [116] compared scenarios for the operation of chillers with and without a storage tank for chilled water in the context of Abu Dhabi to determine that a 30% peak load shaving is possible with the latter scenario. In addition, Tawalbeh et al. [117] analyzed an absorption chiller with lithium bromide as the working fluid that is driven by geothermal or solar energy or waste heat. Recently, Zabala et al. [118] developed a model predictive control for district cooling plants using the Modelica and Python programming languages to find that the power loads of the compressor and absorption chillers were reduced by an average of about 50% when compared to standard control.

The design and operational dimensions of energy conversion technologies are seen to contain important opportunities for reducing energy spending and improving the demand profile. In this special issue, Catrini et al. [119] develop exergoeconomic indicators to guide the decision-making, design, and daily operation of multiple-chiller systems that are applied to a large office building in the Mediterranean climate. The exergoeconomic indicators are used to compare multiple-chiller systems with parallel and series configurations. Each system has different combinations of even or unevenly sized units as part of load sharing strategies with chillers between 50 kW and 550 kW for a total cooling capacity of 750 kW. In the series configuration, each unit enters operation in stages at full or partial load as necessary. The hourly exergoeconomic cost of the chilled water, operational cost for the electricity during operation of the system, including pumps and fans, as well as the investment cost are taken into account. The results indicate that the unevenly sized multiple-chiller systems have advantages over evenly sized multiple-chiller systems with 7.2% and 12.5% lower exergoeconomic costs of chilled water in the parallel and series configuration, respectively. In the lower end of the scenario results for each configuration, the exergoeconomic cost of the chilled water is found to be about 0.85 €/kWh_{ex} and 0.99 €/kWh_{ex}.

Cooling loads in the context of extreme temperatures due to global warming can enter a vicious cycle without more sustainable cooling strategies. Other studies considered alternatives for active cooling technologies, such as Calautit et al. [120] in which a windcatcher that is integrated with heat pipes is developed to ventilate a building with reductions in temperature of up to 10°C in summer months in the United Arab Emirates. In contrast, from a point of view that considers the impacts of climate change, Tettey et al. [121] considered overheating control measures for buildings in Växjö, Sweden under pathways with different climate forcing in the last decade of the 21st century in the years 2090-2099.

4. Integration of energy and water systems

The integration of energy, water and environment systems require research support for tapping into such opportunities as efficient reclamation of energy from wastewater and the utilization of renewable energy in the water sector, including desalination. SDEWES researchers have focused on such needs as a means of advancing energy system integration. Among recent research contributions, Meschede [122] determined the role of the water sector in increasing the potential of shifting demand in islands primarily through water desalination and hydro storage. Other studies included benchmarking the energy performance of 298 wastewater treatment plants in Europe based on such indicators as energy usage per influent biological oxygen demand [123]. It was found that only 8.2% of the wastewater treatment plants were able to reach the highest performance in energy and pollutant removal efficiencies with significant room for improvement, which requires both research and policy support.

As technological options that are at the nexus of energy and water systems in certain aspects, Curto et al. [124] analyzed the integration of PV and wave energy converter to meet the needs of public buildings in a small island in the Tyrrhenian Sea that avoids over 200 tCO_2 per year. Pustina et al. [125] developed a model for optimizing the stability of floating offshore wind turbines to respond to waves and control power fluctuations. In other recent studies, Pantua et al. [126] simulated the impact of high strength winds on roof-mounted solar panels in the typhoon prone region of the Philippines using fluid structure interaction. The results were oriented to guiding urban planners in such aspects as building orientation for the least damage and greatest solar potential. Rusu [127] integrated various climate models when estimating the long-term wave energy potential of the Black Sea leading to the year 2100 also with a seasonal perspective. A similar analysis was conducted for wind fields in the Baltic Sea to find that wind power will increase and slightly decrease in the winter and summer times, respectively, in the next 30 years, which can also provide guidance for floating wind platforms [128]. These interactions underlined the integrated nature of various energy technologies with water as well as environment systems.

The use of diffusers in hydrokinetic and wind turbines received the attention of other researchers in the SDEWES community. In the recent study of Vaz et al. [129], turbines with diffusers were found to increase the rotational speed by 20% when compared to a bare turbine, leading to a net effect of 40% more energy generation despite losses in the powertrain. In the scope of innovative wind technologies, Pavković et al. [130] had optimized the control strategy of a ground station power plant with an ultracapacitor energy storage that is driven by a high-altitude wind energy system. The results had underlined the importance of coordinating the winch servodrive based on the cable tension system in both steady and disturbed wind conditions. Johnston et al. [131] analyzed the limitations of estimating the levelized cost of electricity and its use for determining investment policies for offshore wind given differences in such attributes as water depth, wind energy potential, and distance to central loads. Nezhad et al. [132] used machine learning to determine offshore and near-shore wind potential from satellite data with detailed spatial mapping and application to Sardinia Island and its archipelago.

4.1. Opportunities for wastewater treatment plants

Studies that advance the integration of renewable energy into wastewater treatment processes have received strong research interest within the SDEWES community. Di Fraia et al. [133] had put forth analyses for a system that utilizes biogas for a CHP system while a parabolic trough solar collector field was utilized for extra thermal energy. The results provided important primary energy savings when compared to reliance on electrical energy from the grid, including 14.6% within the analyzed cases with a simple payback period of 3.4 years. In more recent studies, Di Fraia et al. [134] proposed a geothermal energy based wastewater treatment plant that uses renewable energy to meet 100% of its electrical energy demand and to provide heat for sludge drying that is found to save 1.16 kg CO_2 per kg of sludge.

In the recent study of Metolina et al. [135], both the geometric and operational conditions that can increase the performance of fluidized beds for converting wastewater into biogas were determined with a particular focus on biofilm thickness in tapered fluidized beds that can increase biogas production.

The utilization of renewable energy sources to meet the thermal and electrical energy needs of wastewater treatment plants continue to receive strong interest from SDEWES researchers as a productive area for integration. In the present special issue, Di Fraia et al. [136] analyze a geothermal energy based wastewater treatment plant design based on exergoeconomic analysis where geothermal energy is utilized in both the thermal drying process of wastewater sludge and an ORC module for generating electricity for internal use with the surplus being sold to the grid. The exergoeconomic costs relate to the energy and material streams also taking into account the hourly avoided expenses for sludge disposal and electricity purchase, the costs of extraction, and injection related pumping of the geo-fluid for the sustainability of the reservoir as well as revenue from selling electricity to the grid. While the integration of solar energy is more common, the research work indicates that geothermal energy based wastewater treatment plants are feasible from an exergoeconomic point of view, including in the case study located on the island of Ischia in the Campanian Archipelago that serves a population equivalent of about 10,000. The exergy efficiencies are found to be 21.9% for the sludge dryer, 45.2% for the ORC module, and 38.8% for the system. A multivariate optimization to obtain the minimum total exergoeconomic cost on an hourly basis indicates a geofluid temperature of 110°C with 58.9% recycling of the desiccant flow. The results support the integration of geothermal energy in wastewater treatment plants that can also support the transition towards renewable energy islands.

The integration of mass and energy flows to satisfy demands using otherwise wasted resources has been another focus area of SDEWES researchers. The research work in this rich area of cross-fertilization between disciplines has been particularly strong considering opportunities for wastewater treatment plants that can support a circular economy. Among recent studies, Gil-Carrera et al. [137] determined a CO_2 emission savings of 42% during construction and operation when a microbial electrolysis cell is integrated into the biological process in wastewater treatment plants to produce biohydrogen. As alternative options, Grosser et al. [138] experimentally analyzed the anaerobic digestion of wastewater sludge with and without co-digestion with grease trap sludge to find that the co-digestion process increased the biogas production rate by up to 53% with a better removal of volatile solids.

In the present special issue, Di Fraia et al. [139] investigate the valorization of waste vegetable oil as a source of energy supply for a cogeneration system at a wastewater treatment plant that has simultaneous electrical and thermal energy demands. The waste vegetable oil is first compared to the properties of diesel fuel through experimental studies that indicate higher specific fuel consumption for the former. The properties of the waste vegetable oil are then used to propose an alternative system for a wastewater treatment plant in the region of Campania in Italy that serves an area of about 1.2 million inhabitants with 31.9 GWh of electrical energy demand for treating wastewater and dewatering 36.5 ktonne of wastewater sludge per year. The plant currently runs on separate energy generation regimes with electricity purchases from the national grid and natural gas combustion for thermal energy demands. In this context, the proposed system based on waste vegetable oil is compared to the use of natural gas in cogeneration as an additional reference system. The results indicate that the valorization of waste vegetable oil for cogeneration in the wastewater treatment plant can satisfy about 70.0% of the electrical energy demand to run the facility. From an economic and environmental perspective, the levelized cost of electrical energy is 35.0% lower than the cost of electricity from the national grid and CO_2 emissions are 69.9% less than the reference system with 3.68 ktonne CO_2 per year. The benefits of the proposed system also include avoided costs due to the transport and disposal of sludge in landfills since the dewatered sludge at an acceptable moisture content enables opportunities for energy or material reuse. The results of the research work underline the importance of valorizing waste vegetable oil to substitute energy use in high energy demanding facilities, including wastewater treatment plants.

4.2. Integration of solar and wind for water desalination

As consistently upheld by SDEWES researchers since the beginning of this century, the ability to increase flexibility in renewable energy systems requires a diverse and integrated approach across multiple sectors. Scenarios with high penetration of renewable energy continue to elucidate the necessity of such an approach that extends to desalination in the water sector. In this respect, Calise et al. [140] developed a method to better manage the integration of PV panels and water desalination based on reverse osmosis in islands based on water storage, which is applied to Pantelleria Island to obtain 80% water savings. In another study, Calise et al. [141] analyzed a polygeneration system with solar collector driven absorption chillers and renewable heat driven multi-effect distillation for water desalination that is optimized to have a payback period of 2.4 years. Uche et al. [142] experimentally validated a new model for a domestic polygeneration system with PVT panels, evacuated tube solar collectors, a micro-wind turbine, and hybrid desalination based on both membrane distillation and reverse osmosis.

In this special issue, Campione et al. [143] focus on the integration of electrodialysis units with variable renewable energy sources based on a control system that maintains the targeted quality of desalinated freshwater. The system is composed of 4 single pass electrodialysis units that work in parallel to desalinate water from a feed stream of 5 g per liter sodium chloride (NaCl) concentration to 0.25 g per liter while operating based on power from a 45 kW hybrid photovoltaic and wind energy system without electrical storage considering the renewable energy potential of Pantelleria Island. While an emerging desalination technology, electrodialysis is more suitable for flexible operation based on variable renewable energy sources than the more mature reverse osmosis technology. The control system has both feedback and feedforward controllers to adjust the feed flowrate to maintain the necessary NaCl concentration that is satisfied with a maximum fluctuation of ± 10% of the targeted value of 0.25 g per liter at any point in time. Based on the results of the dynamic simulations in this research work, electrolysis systems that are coupled to hybrid photovoltaic and wind energy systems to desalinate water are found to be suitable for flexible operation from small applications up to those for larger sites and small urban areas with several thousand inhabitants and about 800 m^3 per day of freshwater needs.

4.3. Better utilization of salinity gradient technologies

Salinity gradient technologies are emerging technologies with promising potential for utilizing water chemistry. In Giacolone et al. [144], a model for a salinity gradient heat engine based on an ammonium-bicarbonate-water solution with a multi-stage regeneration unit was developed to find an exergy efficiency of 8.5% that can be further improved with the use of advanced membranes. In other recent studies, Giacalone et al. [145] performed an energy and exergy analysis of reverse electrodialysis under various options of system operation, including the salinity of the concentrate feed. In Ortega-Delgado et al. [146], a reverse electrodialysis unit that generates electric power is analyzed from an exergy point of view at various operating and design conditions to determine a global efficiency of 23.8%. Altaee and Cipolina [147] analyzed the process behavior of a full-scale pressure retarded osmosis module to find that the energy output between optimized and un-optimized processes can differ by up to 54%.

Wastewater streams in various industries continue to provide opportunities for SDEWES researchers in advancing methods to better valorize resources. In the present special issue, Safder et al. [148] develop an approach for chemical exergy based pinch analysis to maximize the recovery of chemical exergy that continues to exit through the wastewater streams of the chemical industry. The developed approach uses the concept of chemical exergy to differentiate the chemical potential between sources and sinks and to determine the pinch point considering the available chemical exergy of the wastewater stream. The specific chemical exergy of wastewater streams is calculated based on the chemical oxygen demand while graphical tools for chemical exergy composite curve and cascade analysis are developed. The approach is applied to wastewater streams in a sugar mill industry where the condensate water, washing water of the production line, and/or drainage, including molasses, contains important levels of chemical exergy with the potential of being used in a pressure retarded osmosis system to generate electricity. The scenarios for the sugar mill plant involve a low concentrate, high concentrate, and integrated scenario for all wastewater streams in the sugar mill plant. The results indicate that the sugar mill represents a valuable opportunity to recover chemical exergy to generate up to 3.02 MW and 11.30 MW of power across the three scenarios with the highest power density of 26.05 W/m^2 in the third scenario. The third scenario also represents the lowest levelized cost of electricity among the scenarios and compared options, also including anaerobic digestion, microbial fuel cell, and microbial electrolysis at 0.03 dollar per kWh. The results confirm the importance of the developed approach to evaluate the chemical exergy pinch point of wastewater streams in the chemical industry that represents an untapped energy resource for sustainable power generation and reduced wastewater load.

5. Valorizing heat and thermal management

There are abundant opportunities for utilizing waste heat from industries, data centers, and multiple other sources to displace the use of primary energy sources and renewable energy that can have better uses elsewhere in the energy system. The reuse of unavoidable waste streams is also one of the options for exploiting synergies across sectors. In this context, the principle of enabling a more circular energy system that is centered on energy efficiency as emphasized in the EU Strategy for Energy System Integration [6] requires significant support from the utilization of waste energy resources. Advances in utilizing residual heat have been a key area that has received persistent attention in the SDEWES community due to its role in enabling energy and emission savings based on energy system integration.

5.1. Effective utilization of waste heat and optimization

Various platforms in which the integration of waste heat provides multiple opportunities extend all the way to naval vessels. In this special issue, Barone et al. [149] develop a dynamic simulation model for utilizing low, medium, and high-temperature waste heat that is available onboard while considering changes in climatic conditions as ships navigate the open seas on their travel routes. The model considers the impact of outdoor air temperature, wind speed, humidity, and solar radiation on the ship envelop as well as real time profiles and the availability of waste heat as all engines of the ship are running during cruise hours. The model is applied to the case of a modern cruise ship that navigates the Mediterranean and Caribbean Seas during relevant weeks of the year with about 7000 passengers. In total, 27 energy system layouts with different component sizing are proposed over a reference scenario for valorizing low and medium temperature waste heat sources onboard the ship, particularly the jacket cooling water of the engine. The layouts involve absorption chillers, vapor compression chillers, and/or heat pumps as well as thermally activated multi-stage flash desalination with suitable control logic. In addition to an ORC, another 23 layouts are proposed for utilizing high-temperature waste heat based on cogeneration molten carbonate fuel cells to generate extra electrical energy. Including reference systems that lack any recuperation of waste heat and rely on electricity-driven reverse osmosis and bunkering in ports for freshwater supply, the 50 layouts are analyzed and compared based on primary energy savings, the simple payback period, and the weight of system components. Up to 10.7 ktonne per year of sulfur oxides (SO_x) are avoided alongside other emissions with a downsizing of components due to waste heat utilization and lower system weight. Some of the layouts are found to have lower capital costs than the reference systems while providing for cooling, freshwater, extra electrical energy, and sanitary hot water demands. The results are important for enabling the better integration of energy, water and environmental systems in naval vessles for a more sustainable and efficient naval sector.

The contributions of previous research studies by SDEWES researchers had also focused on improving the energy system of naval vessels since the need for the efficient use of energy is without bound. In Barsi et al. [150], a small-scale combined cycle option with both topping and bottoming cycles were designed for ships with an electrical efficiency of 28.2% and cogeneration efficiency of about 75%. Degiuli et al. [151] modeled the influence of total resistance in waves on fuel consumption in a container ship to find that speeds lower than the design speed can result in about 43.7% lower fuel consumption per route at the same propulsive efficiency while increasing the route duration. These and similar studies can enable avoiding emissions in maritime transport beyond electrification options. Moreover, opportunities for recuperating waste heat based on ORC in space-constrained applications, such as engines on mobile applications, require an optimization approach. In Holik et al. [152], an ORC based system with and without a recuperator was optimized for different working fluids. Based on results on the Pareto frontier, ethanol was found to provide the highest power output when compared to the space requirement of cross-flow heat exchangers and expanders. As other studies with a focus on heat related aspects in transport vehicles, Zou et al. [153] analyzed the optimum heating coefficient of performance for an air-source heat pump with vapor injection for heating in electric railway vehicles.

Among recent studies by SDEWES researchers with a focus on ORC technologies, Varga and Csaba [154] had compared the influence of using different working fluids on the process parameters of maximum power output, heat recovery, cycle efficiency, area requirement, CO_2 emission savings, and payback period. The ranking of the results had indicated that butanes and their mixtures in different mass ratios provided better results than pentanes. Villarini et al. [155] analyzed small-scale solar energy driven ORC systems for trigeneration that involved either compound parabolic collectors or linear Fresnel reflectors. It was also found that energy production can differ by about 19% between two locations in Italy 500 km part, namely Messina and Naples. Among other system designs, Hossin et al. [156] determined the thermodynamic performance of an ORC module that is coupled with an evacuated tube solar collector.

The utilization of low-temperature heat for generating electricity through ORC continues to inspire researchers in their efforts to optimize energy systems. In the present special issue, Anastasovski et al. [157] review approaches that are used to optimize the integration of ORC technologies with process streams based on direct or indirect integration. While pinch technology remains a commonly used approach, its combined use with other optimization approaches is found to be increasing. The review compares approaches based on total site analysis as well as non-linear and linear mathematical programming to optimize design problems that involve ORC technology, including heat exchanger networks. Methods that are used less frequently while providing for optimized solutions include genetic algorithm and artificial neural network, the latter of which is used in the largest ORC system that is integrated into the CHP based district heating system in Lienz, Austria. The different optimization approaches largely focus on modifying ORC architecture and geometry as well as selecting working fluids and sources of waste heat as well as minimizing emissions, maximizing job opportunities, and economic performance. At the same time, it is emphasized that while there are over 700 new ORC installations in recent years, only 13.9% of total ORC installations are related to the use of waste heat in industrial facilities, which is plentiful also in the food and chemical industries. The review underlines that multiple optimization approaches are necessary to allow ORC technologies to better satisfy options in the industry, including batch processes, renewable energy based polygeneration, applications to support wastewater treatment, and water desalination as well as those in communities and smarter urban areas.

5.2. Big data analytics to support cogeneration

Research directions that valorize digital opportunities to support energy system integration include the use of big data analytics for guiding district heating networks, cogeneration, and energy management. Digitalization is also vital for enabling more dynamic and interlinked interactions within the energy system that supports benefits based on system emergence for greater savings in energy and emissions. At the same time, while the use of big data can support more efficient, smarter, and more flexible energy systems, it can also require significant data cleaning. As put forth by recent studies from the SDEWES community, Talent et al. [158] had performed data cleaning of utility level data for electricity, gas, and water usage for Canberra in Australia and put forth valuable advice to increase data quality.

In a digitalizing world, the use of clustering techniques to obtain trends from big data using smart meter inputs provides a valuable opportunity for new research directions, including those that have been pursued by SDEWES researchers. In Gianniou et al. [159], daily load profiles from smart meters in 8293 households in Aarhus, Denmark with connection to district heating were used to determine 5 clusters according to energy use intensity. The results of their research work provided strategic insight into the energy profiles of the households for future planning of the district heating network. Among other data-driven approaches, Markovič et al. [160] developed a technique for data aggregation from smart meters in support of forecasting strategies for residential load profiles. Timur et al. [161] applied artificial intelligence techniques to forecast the mean electrical energy consumption on a monthly basis in a regional hospital. In aspects of building energy management, Wei et al. [162] recently developed a deep learning based approach to predict internal gains from office equipment to reduce energy demands.

Beyond district heating and smart meters, the use of data analytics and machine learning has a potential for being used to support energy savings based on the selection and sizing of cogeneration technology. Vialetto and Noro [163] in this special issue fill the gap for the use of big data to support the integration of cogeneration plants in meeting the energy demand profile of industrial facilities. A clustering technique based on unsupervised machine learning is developed to improve the match between the profile of large industrial facilities and the choice of cogeneration technology. The clustering of a dataset based on 15 minute energy data for both electricity and heat over more than 2 years from an industrial facility that produces wood products is used to apply the innovative technique. The dataset is used to define clusters based on power analysis considering the electric power and the heat-to-power ratio as well as profile analysis for the temporal variation of the energy demand across time. Three different metrics are defined to compare scenarios that follow the electricity or heat demand with heat storage based on the index of saving, index of coverage, and the mean heat stored. The results indicate that 45% of observations are covered in a cluster in which the range of the heat-to-power ratio is between zero and 3.9. A two generator gas micro-turbine with a heat storage system is suggested to better match the profile of the industrial facility that represents a modification of the existing system. The results of the research work are useful to capture additional energy savings, reduce primary energy spending, and minimize economic costs based on the design and operation of cogeneration systems in the industry.

The ability to operate energy intensive industries more flexibly is another valuable option considering that these units can be made to respond to excess electric power supply in feasible ways. In recent studies, Panuschka and Hofmann [164] had optimized the loading and dispatching schedules for thermal energy storage that also depends on the ratio between thermal and electric energy in industrial processes. The characteristics in the model were derived based on the pulp and paper industry.

5.3. Advances in thermal management applications

The hybrid combination of sensible and latent heat storage was proposed by SDEWES researchers as an advanced storage option for better performance. In Ahmed et al. [165], the hybrid sensible-latent heat thermal energy storage configuration provided about 30% higher storage capacity and costs than a sensible rod structure and 22% lower storage capacity with 45% lower costs than the encapsulated PCM. In the scope of thermal management in energy technologies, Ranilović and Grozdek [166] had compared the use of PCM, including cost-effective eutectic options, to protect solar collectors from overheating. Integration of PCM in building envelops were also modeled and validated in seven weather zones [167].

As extensions of these research directions, the selection of PCM for thermal storage can provide benefits for controlling heating in such devices as smart phones, microelectronics, photovoltaics, and lithium-ion batteries. As a means of improving thermal management in such devices and equipment, Xu et al. [168] in the present special issue experimentally compare the heat transfer characteristics of the use of gallium as a heat sink over the use of the more traditional copper foam/paraffin composite heat sink. The experiments are conducted under different heating powers while the spatial distribution of temperature is measured across nine points during the sensible and latent heat storage and overheating stages for both heat sinks. The results indicate that the gallium heat sink provides better performance in controlling the temperature rise of the heating surface based on its heat transfer properties, including times for overall melting and most of the melting. Most importantly, the average melting efficiency is 87.9% that is more than 5 times the average melting efficiency of the traditional heat sink. This efficiency is supported by an effective thermal conductivity that is found to be 71.97 W per m·K as the average value under the applied heating powers between 1.2 and 2.0 W/cm^2. In addition, the gallium heat sink requires 67% less volume and 18% less weight for the same thermal storage capacity when compared to the copper foam/paraffin as the heat sink. The results suggest that it is technically feasible to use gallium for PCM based thermal storage applications in electronic devices and equipment based on its superior performance, especially when further reductions in cost are realized in the future.

Other applications in which thermal management becomes essential are the cabinet cooling systems of telecommunication equipment that is the focus of another research work in the present special issue. While counter-flow heat exchangers are known to provide certain advantages as gas-to-gas plate heat exchangers, cabinet cooling systems are usually constrained in size with dimension restrictions. The influence of system dimensioning on heat exchanger performance in the case of cabinet cooling systems also represents a gap in the scientific literature. To address this gap, Borjigin et al. [169] compare the performance of counter-flow and cross-flow heat exchangers for increments of system length, width, and height based on the effectiveness-number of transfer units and effectiveness-thermal resistance methods. The results indicate that based on increments of system length, the counter-flow plate heat exchanger provides for better performance at larger system length. In contrast, under incremental changes in system width, the cross-flow heat exchanger reaches a cooling capacity of about 176.1 W/K that is 1.3 times greater at a system width of 700 mm. When increments in the height of the cabinet cooling system are considered, the cross-flow heat exchanger is also found to provide for better cooling performance than the counter-flow heat exchanger due to lower dimensionless thermal resistance. According to these results, the characteristics of the dimensioning of the cabinet cooling system in which cross-flow or counter-flow heat exchangers provide better performance are determined. The results of the research work provide a new understanding of the conditions for integrating cross-flow or counter-flow heat exchangers in a more informed manner for efficient cabinet cooling systems.

Other related studies provided advances in the use of thermoelectric modules to convert waste heat into electricity, heat exchangers, or heat transfer. In Dongxua et al. [170], thermoelectric modules with different geometries were found to have important effects on the output power as well as output power per material. Rather than fixed geometries, different couple number and leg length could provide better results with an optimal leg length of 1.1 mm. In addition, Li et al. [171] developed a new method to determine the heat transfer performance of printed circuit heat exchangers with zigzag fins. In the new method, the dimensionless factor of the working point considered the effects of working temperature as well as pressure on heat transfer performance. Katulić et al. [172] determined ways of optimizing the utilization of heat in the bottoming cycle of a combined cycle power plant through exergoeconomic analysis. The study considered the heat recovery steam generator as a heat exchanger network and emphasized that reducing exergy destruction is possible based on the selection of organic working fluids, particularly acetone and R11. In aspects of heat transfer under both 1g as well as microgravity and low-gravity conditions, such as space applications, Li et al. [173] had analyzed a heated enclosure filled with nanofluids based on cases that involve both connected and unconnected heat walls.

6. Modeling for sustainable combustion

Research advances in sustainable combustion have been pioneered by SDEWES researchers over the years leading to continued pioneering research in this field. Among these studies, pioneering advances were put forth by Costa et al. [174] in which the combustion of syngas from biomass gasification in a spark ignition engine within a cogeneration unit was optimized, including spark timing, air-to-fuel ratio, and exhaust gas recirculation, which also impacts emissions. Božić et al. [175] experimentally found that the end-gas temperature profile is the predominant factor for causing a tendency towards knock in spark ignition engines, providing a new understanding towards more sustainable combustion. In other combustion modeling studies, Petranović et al. [176] investigated different strategies for advanced engine operation with and without exhaust gas recirculation and engine boosting. Based on such strategies, the engine brake thermal efficiency of a turbocharged diesel engine was increased to about 31.2%. Jurić et al. [177] developed a radiation heat transfer model to address lower peak temperatures in compression ignition engines that leads to lowered nitrogen oxide (NO) concentrations by about 20% with higher soot concentration. In addition, Jurić et al. [178] investigated combustion characteristics under different injection timing and rail pressure in an experimental unit with a modified engine.

6.1. Performance improvements in combustion technologies

The dedicated research efforts of SDEWES researchers to advance sustainable combustion technologies continue to provide significant contributions. These include the optimization of design decisions for gas turbines as a means of advancing its performance through continuous improvement. In the present special issue, Wang et al. [179] tackle the formation of kidney vortices based on the way that the hot mainstream and the jet flow interact to reduce the effectiveness of film cooling in gas turbines. The factors that can weaken the formation of this vortex include the length of the film cooling injection hole, the inclination angle, and the blowing ratio. These factors are compared for the forward and less analyzed backward injection holes. The standard k-ε turbulence model is used to numerically model the influence of these factors on the kidney vortices while an orthogonal approach based on the Taguchi method with three factors and four levels is used to calculate the adiabatic film cooling effectiveness for specific combinations. The highest film cooling effectiveness is found to be 0.315 in the backward hole configuration with a hole length of 2.5D, an inclination angle of 35°, and a blowing ratio of 2. In this option, the injection hole is able to best weaken the flow strength of vortices so that the jet flow can reattach to the cooling wall after lifting-off from this surface to improve film cooling. Overall, the inclination angle is found to have the greatest effect on the global average film cooling effectiveness that is followed by the blowing ratio and the hole length. In addition, the backward injection hole provides better performance than the forward injection hole at high blowing ratios. Given that the turbine blades of gas turbines can be exposed to temperatures above 2000K, factors that weaken the kidney vortex to increase the effectiveness of film cooling can improve their stable and durable operation. The results of the study provide a computationally effective approach to determine the film cooling effectiveness under three important factors to improve an important attribute for gas turbines.

In other recent studies, Zhang et al. [180] had determined the evolution mechanism of changes in the flame surface and structure during combustion in a low heat value gas engine. The results indicated the importance of ignition positions, the H_2 blending ratio, and the equivalence ratio. Among studies for more efficient combustion processes in natural gas engines, Wang et al. [181] in this special issue design and build a combustion chamber platform for testing the characteristics of turbulent burning under varying conditions with a field of nearly isotropic turbulent flow. The platform includes a digital frequency converter to control motor speed to adjust turbulence intensity to be variable or constant. The study extends a focus on constant turbulence intensity by allowing the turbulence intensity to be changed in the tests and finds that increases in turbulent intensity, all else equal, lead to changes in flame characteristics, including increases in the wrinkles on the flame front, the number of cracks, flame stretch rate, and flame propagation rate. In addition, increases in the turbulence intensity lead to reduced pressure. Under constant turbulence intensity, the fastest flame propagation rate as well as maximum burning pressure and rate of pressure rise takes place when the equivalence ratio is 1.0.

6.2. Pollution minimization and flue gas desulfurization

The aviation sector contains opportunities for the implementation of more sustainable combustion processes alongside other innovations in system design and wing configurations. In the present special issue, Cerinski et al. [182] develop an advanced modeling approach to determine NO formation inside a jet engine combustion chamber to determine possible design modifications to lower emission formation. The approach involves a turbulence model, spray modeling, and the comparison of the general gas phase reaction model with the 3-zones Extended Coherent Flame Model to find that the latter accurately represents the behavior of combustion with less computational expense. The tubular aero-engine combustion chamber is considered to have a single and up to three fuel injection nozzle holes, which effect temperature distribution. The model considers both thermal and prompt formation of NO in a turbulent environment. The results indicate that the jet engine with one nozzle hole has larger sized areas with higher temperature while the temperature is more evenly distributed in three nozzle holed combustion chambers. Since high-temperature regions have an influence on initiating thermal NO formation due to the reaction of molecular air-nitrogen with atomic oxygen, different temperature distributions lower NO concentrations. When compared to those of the single nozzle hole, the mean NO mass fraction inside the combustion chamber is found to be 17% lower in the two nozzle hole and 52% lower in the three nozzle hole results. The study confirms the role of numerical modeling in the early design stage for achieving reductions in NO formation towards more sustainable aviation.

Both pollution avoidance and pollution minimization are necessary considerations for combustion processes. In the present special issue, Bešenić et al. [183] provide a transient simulation approach for wet flue gas desulfurization technologies for industrial spray scrubbing processes, especially for stationary power plants as well as marine sector applications. Rather than the use of scrubbing agents without natural alkalinity, the use of seawater is analyzed due to its absorption capacity and abundance in coastal and offshore applications. Given that the wet flue gas desulfurization process involves the reaction of sulfurous species in the aqueous phase, absorption modeling of both chemical and physical processes is based on aqueous phase chemistry and mass transfer across the phase boundary (interphase). The modeled results at the level of spray droplets are compared with experimental results. The absorption of sulfur dioxide (SO_2) in pure water and seawater sprays at inputs of 500, 700 and 900 ppm is reduced with a removal efficiency of about 97% for seawater absorption and 80% removal efficiency for pure water absorption under a liquid flow rate of about 0.4 m^3 per hour and based on the average concentration 25 cm prior to the outlet. The droplet level modeling approach is found to provide an accurate replication of the experimental data for determining the absorption of SO_2 emissions through industrial scrubbers for better environmental performance and optimization.

Beyond such processes, upgrading of fuel properties based on low-temperature pyrolysis has been researched for its potential impact on reducing particulate matter (PM) emissions. In Wang et al. [184], pyrolysis temperatures between 250 and 350°C were found to provide for the lowest level of fine PM emissions from semi-char combustion as a pollution control measure. Wang et al. [185] also focused on characterizing soot formation as well as gas and tar compositions during the pyrolysis of polyurethane plastics under varying temperatures and volatile residence times. The results had indicated that the soot and gas yields increase with pyrolysis temperature while the reverse is valid for tar and char yields.

7. Sustainable biomass for energy and products

Mobilizing biological wastes and residues across sectors, including agro-food and forestry, is a promising area of action in support of energy system integration. At the same time, the valorization of biomass resources requires continued support from research advances to resolve such aspects as biomass slagging and fouling. In the recent studies of SDEWES researchers, Moço et al. [186] had experimentally investigated the formation of ash deposits when pulverized grape pomace was combusted in a drop tube furnace. The probe exposition time was found to have an important influence on the mass and height of deposits while underlining a frequent need for boiler cleaning. Recently, Aghaalikhani et al. [187] developed a validated method to simulate a 100 kW dual-bed fluidized biomass gasifier including pyrolysis, char gasification, water-gas shift, tar processes, and char combustion reactions and the impact of variations in temperature on the final product. Hu et al. [188] investigated the characteristics of PM emissions from a 30 MW biomass-fired power plant using bark, capsicum, and straw stalks to find low organic and element carbon emissions in the range of 1-3% due to high combustion efficiency.

The utilization of biomass resources in cogeneration or schemes with multiple outputs can represent efficient approaches for satisfying multiple energy demands. In recent studies, La Villetta et al. [189] experimentally analyzed a biomass powered micro-cogeneration unit with a focus on the chemical characteristics of the biomass that is utilized and the syngas that is obtained. Interdependencies were found throughout the process, including those that extend to specific energy demands. Moore et al. [190] had analyzed scenarios for cogeneration from bagasse and straw from a life cycle assessment perspective to determine the influence of such process conditions as boiler output vapor pressure, straw moisture content, and biomass addition rate on both energy and environmental performance.

Other recent studies from SDEWES researchers relate to biogas upgrading, biorefineries, and advanced liquid biofuels. The recent study of Corbellini et al. [191] developed a novel progress for upgrading biogas into biomethane based on a two-stage thermophilic reactor process. The microbiome in the reactors was analyzed to determine that hydrogen assisted methanogenesis can optimize the process to reach a maximum methane content of 95%. Stančin et al. [192] reviewed the role of alternative fuels, including biofuels, in transitioning the transport and industry sectors towards decarbonization while emphasizing the need for production pathways that are coupled with intermittent renewable energy sources. Cardona Alzate et al. [193] reviewed 13 biorefineries around the world to determine the extent of applying a portfolio with multiple products related to energy, materials, chemicals, food, and feed while avoiding a repetition of the pitfalls of crude-oil refineries. Seljak et al. [194] reviewed the utilization of bioliquids as an energy carrier, including highly viscous bioliquids from low-cost feedstock, for enabling the circular use of both materials and resources towards zero-waste targets in society.

7.1. Gasification of lignocellulosic feedstock

The exploitation of lignocellulosic feedstock in fixed bed updraft gasifiers represents one of the second-generation options for utilizing biomass. When compared to a downdraft gasifier, an updraft gasifier has higher thermal efficiency and greater flexibility for feedstock while requiring a syngas cleaning system due to the higher tar content. In the present special issue, Cerone et al. [195] conduct an experimental analysis of the spatial variation of syngas composition along the height in the reactive biomass bed and its coupling with the thermal profile along the same height from the grate. The study advances the more limited understanding of the syngas composition at the outlet of the gasifier only. The experiments are based at a small scale pilot facility with a 20-30 kg per hour of lignocellulosic feedstock using almond shells as residue from the agrofood industry. The greatest spatial variation along the gasifier height is found to be the increase in light hydrocarbons, particularly CH_4, which is correlated with residence time. The results are also compared for a gasification process with and without the injection of overheated steam at 160°C. The cold gas efficiency is found to be 67.0% in air gasification and 72.5% in air/steam gasification with the highest H_2/CO molar ratio of 0.77 in the latter. Small scale updraft gasifiers are gaining increased attention, also for supporting smart energy districts, and the research work advances the field of biomass gasification for producing syngas that is also upgradable to synthetic natural gas.

Other recent studies by SDEWES researchers had explored biomass-based systems exclusive of such a focus. Zadravec et al. [196] developed a computational fluid dynamics based approach to predict the pattern of lengthwise biomass conversion and syngas gas temperature along a 13MW_{th} waste wood-fired grate boiler. Golub et al. [197] determined the optimal height to diameter ratio of the recovery zone in a downdraft biomass gasifier for higher quality, higher concentration producer gas. Mikulandrić et al. [198] developed a model to predict changes in syngas temperatures under different operating conditions as well as syngas composition based on training data from a 75 kW_{th} fixed bed biomass gasification plant in Dresden, Germany. As a result, the contribution in the present special issue represents an advance for the field, also considering the focus on lignocellulosic feedstock.

In aspects that are related to feedstock in support of biomass utilization pathways, recent studies include those of Lovrak et al. [199] in which a geographic information system (GIS) oriented approach was developed to determine the spatial distribution of lignocellulosic and non-lignocellulosic agricultural residues and organic municipal waste under seasonal variations. The application of this approach in the context of Croatia indicated between 12% to 40% difference with annual estimates of biomass feedstock for biogas production. Manić et al. [200] examined the kinetic parameters of slow pyrolysis of apricot kernel shells as lignocellulosic feedstock that is dominated by cellulose decomposition reactions.

7.2. Catalysts for biomass-based engine fuels

The efficiency and cost effectiveness of producing biomass-based engine fuels from Fischer-Tropsch synthesis remains open to improvement. This opportunity has motivated SDEWES researchers in the present special issue to test the addition of metal supported catalysts to the less valuable fraction of the process that is known as Fischer-Tropsch wax to increase the yield of engine fuel components. In the experimental analysis of Tomasek et al [201], the hydrocracking results of two types of biomass-based Fischer-Tropsch wax feedstock that contain a higher and lower molecular weight of hydrocarbons are compared with the addition of two platinum catalysts that are supported by zeolite mordenite and tungstated zirconia. The results of the experiments with catalytic mixtures in the temperature range of 300-350 °C and H_2 to hydrocarbon volume ratio of 600 indicate that the tungstated zirconia supported platinum catalyst provides higher yields of gasoline, jet, and gas oil fractions from both types of biomass-based Fischer-Tropsch wax feedstock. A higher yield is obtained from the wax with a higher molecular weight of hydrocarbons. These results contribute to making additional progress in the field by maximizing and upgrading biomass-based engine fuel fractions from Fischer-Tropsch synthesis.

In other recent studies that involved catalysts or fuel mixtures, Kim et al. [202] had compared the formation efficiency of aromatic hydrocarbons from two wood polymer composites with different polymer contents using different catalysts. The hierarchical desilicated mesoporous catalyst of HDMZSM-5 was found to provide the highest efficiency for aromatic formation. In the scope of catalytic conversion methods, Tóth et al. [203] developed an approach for co-processing mixtures with fractions of waste fatty acids and unrefined gas oil to produce fuel blending bio-paraffin components with lower pollutants. Chen et al. [204] investigated the use of nanoparticles in diesel fuel blends to reduce the brake specific fuel consumption, lower emissions, and increase efficiency. Carbon nanotube blends were found to improve brake specific fuel consumption by up to 19.9% with more limited benefits on emissions while aluminum oxide and silicon oxide blends had lower results for hydrocarbon emissions.

7.3. Sustainable use of biomass resources and residues

The sustainable collection and utilization of biomass represents a concern that has received attention from the SDEWES research community. Ferla et al. [205] developed a GIS-based tool to determine the potential of urban biowaste from pruning of public urban greenery in biomass-to-energy schemes. The application of the tool to Milan validated the results by determining a potential of about 25 thousand tonnes from one annual pruning cycle that can be used in a biomass-based district heating plant. Aberilla et al. [206] focused on the use of biomass in agricultural villages in Southeast Asia based on the direct combustion and gasification of rice and coconut residues and anaerobic digestion of livestock manure and their comparison with a diesel generator to find significant environmental benefits. Jarrar et al. [207] compared anaerobic digestion processes in dairy farms that represent different systems in Jordon and found that the payback period can be reduced by 37.3% based on policy design.

In the present special issue, Fan et al. [208] develop a decision-making support tool to account for the burdening, unburdening, and biogenic emissions of biomass utilization pathways under more dynamic baseline conditions. The developed approach allows for the comparison of the emission-cost nexus based on emissions from biomass production, conversion processes, sequestration, and indirect emissions under different local and policy conditions. The case study that is used to demonstrate the approach involves an energy crop (switchgrass), agricultural waste (corn stover), and municipal waste (mixed plastic waste). Their conversion is based on slow pyrolysis for producing energy to displace the use of existing energy resources with products of syngas and bio-oil or producing biochar to provide for carbon sequestration. The approach indicates that the results vary depending on the cost of greenhouse gas emissions, the carbon intensity of the energy mix, and the use of the biomass to satisfy increasing or baseline energy demand. The approach also considers a multiplier for the impact of soil-biochar interactions, such as the stability of the biochar, its application in soil with low versus high quality, and fertilizer usage. The results of the research work emphasize that undiscriminating the emissions of biomass pathways also in contexts with a relatively higher value of producing energy versus the cost of greenhouse gas emissions will misinform decision-makers. The results of the research work are useful for comparing techniques toward managing carbon from biomass pathways more effectively.

The combustion of biomass in grate furnaces is also receiving increasing attention due to its higher feedstock flexibility. At the same time, fly ash and slag are produced as the solid residues of this process with about 60-70% slag and 30-40% fly ash. In the present special issue, Wang et al. [209] investigate the total content and leaching rate of major elements and trace elements as well as the unburned carbon content of solid residues from four biomass-fired power plants with grate furnaces in Henan Province, China. The feedstock of these biomass power plants mostly with capacities of 30 MW contains mixtures of bark and stalks of capsicum and straw. Based on fly ash samples that are collected after the flue gas condenser and slag that is collected from scraper conveyors, the top four mineral elements in fly ash are found to be potassium, silicon, calcium, and chlorine with similar or slightly lower content in slag except for potassium, sulfur and chlorine, which is significantly lower. Unburned carbon content varies by more than 2 fold for fly ash when measured at temperatures between 550 and 815°C while relatively stable for slag. The findings indicate that both fly ash and slag from the four power plants do not have leaching toxicity under the leaching conditions of the research work and are suitable for being reused for land based applications in different ways. Fly ash is more suitable to be used to produce potassium rich liquid fertilizer rather than direct soil fertilizer. Based on lower leaching rates for traces of heavy metals, slag is found to be more suitable for direct use as soil additives for agricultural as well as forested lands.

These contributions take place alongside other studies by SDEWES researchers, including Medeiros Silva et al. [210] in which the use of chemical and biosolid fertilizers in sugarcane cultivation was compared based on life cycle assessment. In this study, greenhouse gas emission reductions of 26.5% were found for the use of biosolids in the Brazilian context with additional benefits for productivity. Among the multiple studies that focus on biomass pyrolysis, Luz et al. [211] had recently developed a model for determining the heat transfer mechanisms in the fast pyrolysis of spent coffee grounds in a screw reactor. Spent coffee grounds represent a significant source of waste in the food sector. The results for optimizing the process yield for bio-oil from this source of waste was found to be observed at 500°C.

8. Managing and utilizing emissions

The EU Energy Integration Strategy foresees that carbon capture and storage technologies can have a role in supporting unavoidable emissions in climate-neutral energy systems [6]. Research contributions from the SDEWES community have prepared the basis for multiple options, including carbon utilization. In Sedlar et al. [212], the re-purposing of natural gas offshore platforms into platforms for renewable energy and the blue economy was also explored based on 19 offshore facilities in the North Adriatic. In addition, as part of recent studies that focused on managing emissions, Ortiz et al. [213] developed a method to account for exergy costs and CO_2 emissions, also differentiating the renewable and non-renewable components. In the context of the existing electricity mix of the Netherlands, non-renewable components were found to account for 67% of the total unit exergy costs, requiring a paradigm shift.

8.1. Alternatives for conventional fuel production

Within the ongoing energy transition, energy conversion processes for conventional energy sources are being questioned with multiple alternatives. Among recent studies, Khor et al. [214] compared options for recovering the output of cold energy from liquefied natural gas (LNG) facilities for applications that require cold energy, such as air separation units, producing dry ice, and district cooling. The comparison of such options indicated that CO_2 emissions can be reduced by up to 38.0% when utilized in such applications under the analyzed cases while displacing the need to use electricity for re-producing the cold energy. In Interlenghi et al. [215], a supersonic separator was proposed for a process that involved complete capture of post-combustion carbon emissions in a gas-to-wire concept for offshore platforms.

In the present special issue, Interlenghi et al. [216] perform a techno-economic analysis of the use of supersonic separators for the small scale production of LNG. The liquefaction of natural gas represents a single-feed, single-product process that is power-intensive with the electric power being used for various compressors and compression trains as well as cooling water for intercoolers. The possible conversion processes include the use of the Joule-Thomson effect and turbo-expanders that are also compared to the newer focus on the use of supersonic separators. The three conversion processes are compared based on thermodynamic efficiency, the power intensity, and the net present value. The use of the Joule-Thomson effect is found to have the most inefficient performance while the turbo-expander has a slightly better performance than the supersonic separator from a technical and environment point of view with the reverse being true for the economic performance. The thermodynamic efficiency of the options ranges from 6.2% to 12.2%, the power intensity ranges between 0.87 kWh and 1.74 kWh per kg of produced LNG, and the net present value has a 5 fold difference. The compared results can also be used when renewable energy based fuels are compared to those from conventional energy sources.

8.2. Carbon capture, storage and utilization

Research directions that enable greater opportunities for carbon capture, storage, and utilization have the potential to support decarbonization options. In this context, SDEWES researchers conceived and developed new approaches to improve the conversion process of energy, emissions, and materials. In the scope of oxy-combustion technologies for carbon capture and storage, the experimentally validated numerical model of Jovanović et al. [217] indicated that optimizing burner aerodynamics enabled stable and efficient operation, including during phases that require switching to air combustion. As a study that focused on oxyfuel capture, Brigagão et al. [218] optimized the air separation unit that is the most energy and cost-intensive component of the process. A newly developed cryogenic distillation column with top-vapor recompression was found to require 139.0 kWh per tonne of oxygen at 95%mol. Poblete et al. [219] analyzed a biogas driven combined cycle power plant with post-combustion carbon capture and storage to find a positive net value, especially in the case of carbon taxation. Carminati et al. [220] analyzed options to retrofit a conventional sugarcane biorefinery with 93% post-combustion capture of flue gas CO_2 emissions into a concept that with a net present value 9.8 times higher than the base case.

Recent contributions further extended to studies where fly ash was utilized for thermal energy storage material. In Lin et al. [221], a process based on radio frequency plasma was found to provide a suitable option for converting coal biomass fly ash into valuable material for sensible heat storage with a double benefit for the environment and energy flexibility. In the present special issue, Pacheco et al. [222] further focus on chemicals that are produced from the use of CO_2 as raw material as a means of supporting CO_2 utilization processes. Since experimental data for the thermochemistry of products that are derived from CO_2 are limited, the study develops a computational method based on semi-empirical quantum chemistry to minimize the binding energy of molecules in CO_2 derived products. In total, the optimal structures of 122 chemical species across 16 chemical classes are analyzed to improve chemical product design. The semi-empirical method is found to predict the enthalpy of formation and entropy with accuracy and reliability across the chemical classes where 59% are endothermic reactions and 41% are exothermic reactions. The results emphasize the multi-disciplinary nature of efforts for increasing the sustainability of energy conversion processes, including the stage of CO_2 utilization technologies.

9. Discussion and Multi-Disciplinary Interrelations

The advances that are contained in the 29 contributions of this special issue provide results that will have significant implications for the implementation of the EU Energy Integration Strategy and any similar directions towards integration around the world. In providing these contributions, cross-cutting perspectives on integration internally connect the research work of these studies and represent multi-disciplinary interrelations among the seven different themes of this editorial. Table 1 summarizes the 29 new articles to emphasize these interrelations with perspectives that exceed any single focus in any theme towards a coherent outlook for the integration of energy, water and environment systems.

Multi-disciplinary interrelations further arise with the scientific programme of the 14th Conference on SDEWES that was enriched with 4 invited plenary lectures and 17 special sessions. Among the invited plenary lectures, Prof. Christian Breyer from Lappeenranta University of Technology [223] characterized four key enabling technologies for the survival of human civilization, namely solar photovoltaics, wind turbines, batteries, electric vehicles, and power-to-X technologies. An integrated transition for long-term sustainability is necessary for mitigating emissions, climate impacts, and risks of exceeding planetary boundaries all at the same time. In turn, these technologies have a key role in the energy transition towards 100% renewable energy systems. The results were based on an original energy system transition model at hourly resolution across 145 sub-regions of the world considering 106 technologies and storage options for integrating power, heat, transport as well as desalination [224]. The model has also been elaborated for multiple countries and regions from Europe [225]and the Americans [226] to Middle East and North Africa [227] with co-benefits, including job creation [228]. In contrast to the limitations of the existing energy system, the rise of electricity as a universal platform based on low-cost electricity from renewables by 2050 was found to lead to overall efficiency gains. For this reason, total primary energy demand increased by only 21% despite a much higher increase in energy services.

There is a growing knowledge base for 100% renewable energy systems [229], including pivotal contributions from SDEWES researchers. In this context, the technologies and approaches that are covered by the research advances in this special issue, particularly those that relate to flexibility and integration in the energy system, have a similar role in supporting a more sustainable energy future. Another invited plenary lecture by Prof. Henrik Lund from Aalborg University [230] centered on the role of smart energy systems for a 100% renewable energy future with connections of such strategies at the local, national and European levels as well as worldwide. Ways of integrating renewable energy in smart energy systems beyond a focus on electricity to include heating, cooling, buildings, industry, and transport require a cross-sector approach. The lecture provided criteria for designing smart energy cities in the context of 100% renewable energy targets with options for reducing system costs, including hourly load balancing based on smart charging of electric vehicles, batteries, steam storage, and flexible electrolyzers. The case of transitioning the local energy system of Aalborg into 100% renewable energy based on “Smart Energy Aalborg” considering the IDA Energy Vision 2050 for Denmark gave a clear example of the available opportunities for cities, including solutions as advanced in this special issue.

On the side of energy transition solutions for industrial actors, the invited plenary lecture by Prof. Robin Smith from the University of Manchester [231] focused on future industrial energy systems and provided a new framework for their design and optimization. The framework allows for considering the site profiles and local power-to-heat ratio of industries in the process of developing roadmaps for switching to renewable energy and waste-to-energy systems. Flexible CHP concepts, renewables, waste, and energy storage were emphasized within a superstructure of components and seasonal variations. The energy, food and water nexus was also underlined when considering a mix of renewable energy sources to satisfy the mix of high-temperature heat demands as well as electricity demands in energy intensive industries. The lecture directly relates to other contributions in the special issue, particularly the use of big data analytics for guiding more informed cogeneration decisions in the industry [163].

Table 1. Summary of the research focus and original contributions of the articles in this special issue

Theme	Reference	Research focus and original contributions
Advances in energy system integration	El Fouas et al. [42]	A dynamic numerical model for PVT plant performance in real operational environment
	Ocłoń et al. [43]	Numerical model and optimization of cooling segments in sun-tracking solar panels
	Alahmer and Ajib [45]	Technological advances in solar cooling technologies and optimization approaches
	Khor et al. [50]	Granular materials for macro-encapsulated PCM packed beds in cold storage tanks
	Ancona et al. [59]	Renewable energy-based advanced P2G system configurations at off-design conditions
	Fichera et al. [63]	Agent-based model for electricity exchanges among prosumers in urban buildings
Urban synergies in the energy transition	Calise et al. [95]	Innovative system designs involving solar energy and heat pumps for district areas
	Barone et al. [109]	A dynamic simulation model for optimizing new DHC or retrofitting existing networks
	Allen et al. [113]	Coupling of radiant heating and cooling systems with DHC connection typologies
	Catrini et al. [119]	Exergoeconomics of multiple-chiller systems with parallel or series configuration
Integration in energy and water systems	Di Fraia et al. [136]	Exergoeconomic optimization of geothermal energy for wastewater treatment plants
	Di Fraia et al. [139]	Valorization of waste vegetable oil for cogeneration in wastewater treatment plants
	Campione et al. [143]	Control system for flexible operation of electrodialysis units driven by renewables
	Safder et al. [148]	Chemical exergy based pinch analysis and pressure retarded osmosis in industry
Valorizing waste heat and thermal management	Barone et al. [149]	Simulation of waste heat utilization in cruise ships for energy and freshwater supply
	Anastasovski et al. [157]	Review of optimization approaches for integrating ORC technologies in process streams
	Vialetto and Noro [163]	Clustering based on machine learning for better integration of cogeneration in industry
	Xu et al. [168]	Gallium based PCM thermal storage for controlling heating in devices and equipment
	Borjigin et al. [169]	Cross-flow and counter-flow heat exchanger performance for cabinet cooling systems
Modeling for sustainable combustion	Wang et al. [179]	Modeling of kidney vortices and increasing film cooling effectiveness in gas turbines
	Wang et al. [181]	Combustion chamber with variable turbulence intensity for testing turbulent burning
	Cerinski et al. [182]	Advanced modeling approach for NO formation during tubular aero-engine combustion
	Bešenić et al. [183]	Transient simulation of wet flue gas desulfurization for industrial spray scrubbing
Sustainable biomass for energy and products	Cerone et al. [195]	Spatial variation of syngas composition in updraft gasifiers with lignocellulosic feedstock
	Tomasek et al [201]	Platinum catalyst mixtures for hydrocracking of biomass-based Fischer-Tropsch wax
	Fan et al. [208]	Decision-making support tool for differentiating emissions of biomass utilization
	Wang et al. [209]	Composition of solid residues from biomass-fired grate furnaces and leaching rates
Managing and utilizing emissions	Interlenghi et al. [216]	Performance of supersonic separators in conversion processes for LNG production
	Pacheco et al. [222]	Computational method for minimizing molecular binding energy in CO_2 products

Among the total of 17 special sessions, polygeneration systems, thermoeconomic analyses, and optimization was the focus of the special session on “Small and large scale polygeneration for an efficient and sustainable energy conversion and supply in single users and small districts” that was organized with the collaboration of Prof. Francesco Calise from the University of Naples Federico II, Prof. Antonio Piacentino from the University of Palermo, and Prof. Laura Vanoli from Università degli Studi di Napoli Parthenope. Related contributions take place in this special issue based on [63], [139], [143] and [149]. Advances in sustainable combustion as represented in [169], [182], [183] and [209] of this special issue were undertaken in the special session on “Sustainable multiphase reactive processes” that was co-organized by Prof. Milan Vujanović from University of Zagreb and Prof. Mário Costa from Instituto Superior Técnico who will be remembered for his leading contributions to sustainable combustion.

The special session on “Renewable energies, innovative HVAC systems and envelope technologies for the energy efficiency of buildings” as organized by Prof. Soteris Kalogirou from Cyprus University of Technology together with Prof. Annamaria Buonomano and Prof. Adolfo Palombo from the University of Naples Federico II are represented in this special issue with related advances in [42], [109] and [113]. In addition, the special session on “Integration of smart cities and smart Industry for circular economy” that was co-organized by Dr. Yee Van Fan, Dr. Petar Sabev Varbanov, and Prof. Jiří Jaromír Klemeš from Brno University of Technology focused on opportunities for energy, water, and waste to secondary raw material as represented in [168] and [208]. Solutions for integration in hot climates was the focus of another special session on "Sustainable enhancements of power, cooling and water for hot climates" that was co-organized by Dr. Valerie Eveloy from Khalifa University, Prof. Ricardo Chacartegui from University of Sevilla, and Dr. Alessandro Romagnoli from Nanyang Technological University with [45] taking place in this special issue. The special session on “High temperature heat transfer process and enhancement” that was co-organized by Prof. Ting Ma, Prof. Jian Yang, and Prof. Qiuwang Wang from Xi'an Jiaotong University focused on advances in heat transfer, such as in [169] in this special issue.

10. Conclusions and Future Outlook

The scientific knowledge that is synthesized in this editorial with a focus on the 29 research articles in this special issue underlines the central focus of integration upon which the SDEWES Conference series was initiated. With an emphasis on coordination and synergies between sectors now forming the basis of the new EU Strategy for Energy System Integration [6], the contributions that have been put forth by the SDEWES researchers persistently over the years are even more pivotal. Steering the future of civilization and the planet towards the sustainable development of energy, water and environment systems, based on the research directions of the SDEWES community as represented in this editorial, will necessitate continued interactions to accelerate the impact these advances can bring.

With the central focus on integration, the research articles in this special issue represent multiple advances across the strategic necessities for the energy transition. The first main theme of energy system integration includes a review of research articles that contribute to advances in solar energy technologies. Innovations in PVT plants [42], sun-tracking solar panels with cooling [43], and solar cooling technologies [45] are put forth as a means of supporting the leading role of solar energy in the energy transition. The first theme further addresses technological advances in thermal energy storage based on advanced PCM packed beds [50] while reaching to the essential research area of power-to-X technologies for system flexibility based on a P2G system [59]. Moreover, the empowerment of prosumers in the energy transition is given research support based on an agent-based model [63].

These research contributions lead to the second theme on urban interactions and synergies considering that the urban context provides key assets in supporting opportunities for integration towards realizing the energy transition. Innovative systems that provide an integration of renewable energy in urban infrastructure are analyzed [95]. Based on the role of DHC networks for integration, other contributions provide advances for guiding the characteristics of new and existing DHC networks [109] as well as efficient means for their connection to building level heating and cooling systems [113]. Design and operational decisions are further considered for cooling applications in the urban context [119].

Perspectives on effective integration in energy and water systems as the third theme provide multiple opportunities for wastewater treatment plants, including those based on geothermal energy [136] and waste vegetable oil [139] as put forth in this special issue. The integration of solar and wind for water desalination is also advanced with a control system [143] while a better utilization of salinity gradient technologies is enabled with a chemical exergy based approach [148]. As another crucial aspect, contributions for the effective utilization of waste heat and optimization are provided for the energy system of cruise ships [149] as well as the integration of ORC in various process streams [157]. Big data analytics to support cogeneration [163] and thermal management applications for devices and equipment [168], [169] take place as advances within the fourth theme that focuses on waste heat.

Advances in modeling for sustainable combustion are upheld in the fifth theme based on performance improvements for gas turbines [179] and gas engines [181] as well as means for pollution minimization in tubular aero-engines for more sustainable aviation [182]. Industrial spray scrubbing processes for power plants and marine applications also underline opportunities on the path to decarbonization in these sectors [183]. As the sixth of seven themes in this editorial, advances in sustainable biomass for energy and alternative products are based on gasification options for lignocellulosic feedstock [195], catalysts for biomass-based engine fuels [201], a decision-making support tool [208], and analyses towards the reuse of solid residues from biomass combustion [209] that supports a circular approach. As the seventh theme, contributions include those for managing emissions [216] and CO_2 utilization [222].

The guest editors observe significant potential for the advances in this special issue and trust that these research articles will be of utmost relevance to readers of *Energy Conversion and Management*. Advances in energy system integration at the research and policy levels will be crucial for enabling a renewable energy transition that is a prerequisite towards climate neutrality for a sustainable future.

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References

[1] Lenton TM, Rockström J, Gaffney O, Rahmstorf S, Richardson K, Steffen W, et al. Climate tipping points — too risky to bet against. Nature 2019;575:592–5.

[2] IPCC. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. 2018.

[3] Van Vuuren DP, Stehfest E, Gernaat DEHJ, Van Den Berg M, Bijl DL, De Boer HS, et al. Alternative pathways to the 1.5 °c target reduce the need for negative emission technologies. Nat Clim Chang 2018;8:391–7. doi:10.1038/s41558-018-0119-8.

[4] Roelfsema M, van Soest HL, Harmsen M, van Vuuren DP, Bertram C, den Elzen M, et al. Taking stock of national climate policies to evaluate implementation of the Paris Agreement. Nat Commun 2020;11:1–12. doi:10.1038/s41467-020-15414-6.

[5] International Centre for Sustainable Development of Energy, Water and Environment Systems n.d. https://www.sdewes.org/.

[6] European Commission. Powering a climate-neutral economy: An EU Strategy for Energy System Integration. 2020. doi:COM(2020) 299 final.

[7] Sustainable Development of Energy, Water and Environment Systems 2019 n.d. https://www.sciencedirect.com/journal/energy-conversion-and-management/special-

issue/102F43VFG1K.
[8] Duić N, Rosen MA. Sustainable development of energy systems. Energy Convers Manag 2014;87:1057–62. doi:https://doi.org/10.1016/j.enconman.2014.08.046.
[9] Krajačić, G.; Duić, N.; Rosen M. Sustainable development of energy, water and environment systems. Energy Convers Manag 2015;92:241–3. doi:10.1016/J.ENERGY.2015.10.035.
[10] Krajačić G, Duić N, Vujanović M, Kılkış Ş, Rosen MA, Al-Nimr MA. Sustainable development of energy, water and environment systems for future energy technologies and concepts. Energy Convers Manag 2016;125:1–14. doi:10.1016/j.enconman.2016.08.050.
[11] Krajačić G, Vujanović M, Duić N, Kılkış Ş, Rosen MA, Ahmad Al-Nimr M. Integrated approach for sustainable development of energy, water and environment systems. Energy Convers Manag 2018;159:398–412. doi:https://doi.org/10.1016/j.enconman.2017.12.016.
[12] Kılkış Ş, Krajačić G, Duić N, Rosen MA, Al-Nimr MA. Advancements in sustainable development of energy, water and environment systems. Energy Convers Manag 2018;176:164–83. doi:10.1016/J.ENCONMAN.2018.09.015.
[13] Kılkış Ş, Krajačić G, Duić N, Montorsi L, Wang Q, Rosen MA, et al. Research frontiers in sustainable development of energy, water and environment systems in a time of climate crisis. Energy Convers Manag 2019;199:111938. doi:10.1016/j.enconman.2019.111938.
[14] Duić N, Krajacic G, Da Graca Carvalho M. RenewIslands methodology for sustainable energy and resource planning for islands. Renew Sustain Energy Rev 2008;12:1032–62. doi:10.1016/j.rser.2006.10.015.
[15] Mathiesen B V., Lund H, Connolly D, Wenzel H, Ostergaard PA, Möller B, et al. Smart Energy Systems for coherent 100% renewable energy and transport solutions. Appl Energy 2015;145:139–54. doi:10.1016/j.apenergy.2015.01.075.
[16] Connolly D, Lund H, Mathiesen B V, Werner S, Möller B, Persson U, et al. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 2014;65:475–89. doi:https://doi.org/10.1016/j.enpol.2013.10.035.
[17] Meschede H, Esparcia EA, Holzapfel P, Bertheau P, Ang RC, Blanco AC, et al. On the transferability of smart energy systems on off-grid islands using cluster analysis – A case study for the Philippine archipelago. Appl Energy 2019;251:113290. doi:10.1016/j.apenergy.2019.05.093.
[18] Meschede H. Analysis on the demand response potential in hotels with varying probabilistic influencing time-series for the Canary Islands. Renew Energy 2020. doi:https://doi.org/10.1016/j.renene.2020.06.024.
[19] Bertheau P. Supplying not electrified islands with 100% renewable energy based micro grids: A geospatial and techno-economic analysis for the Philippines. Energy 2020;202:117670. doi:10.1016/j.energy.2020.117670.
[20] Lund H. Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach. Energy 2018;151:94–102. doi:10.1016/J.ENERGY.2018.03.010.
[21] Seefried A, Müller B, Förster E. Regional analysis of potentials of flexibility options in the electricity system for the study regions Prignitz in Brandenburg and Anhalt-Bitterfeld-Wittenberg in Saxony-Anhalt. J Sustain Dev Energy, Water Environ Syst 2020;8:162–83. doi:10.13044/j.sdewes.d7.0277.
[22] Moser M, Gils H-C, Pivaro G. A sensitivity analysis on large-scale electrical energy storage requirements in Europe under consideration of innovative storage technologies. J Clean Prod 2020:122261. doi:10.1016/j.jclepro.2020.122261.
[23] Jimenez-Navarro J-P, Kavvadias K, Filippidou F, Pavičević M, Quoilin S. Coupling the heating and power sectors: The role of centralised combined heat and power plants and district heat in a European decarbonised power system. Appl Energy 2020;270:115134.

doi:https://doi.org/10.1016/j.apenergy.2020.115134.
[24] Pfeifer A, Krajačić G, Ljubas D, Duić N. Increasing the integration of solar photovoltaics in energy mix on the road to low emissions energy system – Economic and environmental implications. Renew Energy 2019;143:1310–7. doi:10.1016/j.renene.2019.05.080.
[25] Pfeifer A, Krajačić G, Haas R, Duić N. Consequences of different strategic decisions of market coupled zones on the development of energy systems based on coal and hydropower. Energy 2020:118522. doi:https://doi.org/10.1016/j.energy.2020.118522.
[26] Taseska-Gjorgievska V, Todorovski M, Markovska N, Dedinec A. An integrated approach for analysis of higher penetration of variable renewable energy: Coupling of the long-term energy planning tools and power transmission network models. J Sustain Dev Energy, Water Environ Syst 2019;7:615–30. doi:10.13044/j.sdewes.d7.0264.
[27] Pavičević M, Quoilin S, Zucker A, Krajačić G, Pukšec T, Duić N. Applying the dispa-SET model to the western balkans power system. J Sustain Dev Energy, Water Environ Syst 2020;8:184–212. doi:10.13044/j.sdewes.d7.0273.
[28] Macenić M, Kurevija T, Medved I. Novel geothermal gradient map of the Croatian part of the Pannonian Basin System based on data interpretation from 154 deep exploration wells. Renew Sustain Energy Rev 2020;132:110069. doi:https://doi.org/10.1016/j.rser.2020.110069.
[29] Mabrouk S Ben, Favuzza S, La Cascia D, Massaro F, Zizzo G. Energy management of a hybrid photovoltaic-wind system with battery storage: A case report. J Sustain Dev Energy, Water Environ Syst 2019;7:399–415. doi:10.13044/j.sdewes.d6.0233.
[30] Saracevic E, Theuretzbacher F, Woess D, Friedl A, Miltner A. Economic and technical evaluation of flexible power generation scenarios for a biogas plant. J Sustain Dev Energy, Water Environ Syst 2020;8:328–43. doi:10.13044/j.sdewes.d7.0289.
[31] Mauleón I. Optimizing individual renewable energies roadmaps: Criteria, methods, and end targets. Appl Energy 2019;253:113556. doi:10.1016/j.apenergy.2019.113556.
[32] Ribó-Pérez D, Bastida-Molina P, Gómez-Navarro T, Hurtado-Pérez E. Hybrid assessment for a hybrid microgrid: A novel methodology to critically analyse generation technologies for hybrid microgrids. Renew Energy 2020;157:874–87. doi:https://doi.org/10.1016/j.renene.2020.05.095.
[33] Roselli C, Diglio G, Sasso M, Tariello F. A novel energy index to assess the impact of a solar PV-based ground source heat pump on the power grid. Renew Energy 2019;143:488–500. doi:10.1016/j.renene.2019.05.023.
[34] Calise F, Cappiello FL, Dentice d'Accadia M, Vicidomini M. Energy and economic analysis of a small hybrid solar-geothermal trigeneration system: A dynamic approach. Energy 2020;208:118295. doi:https://doi.org/10.1016/j.energy.2020.118295.
[35] Anastasovski A, Rašković P, Guzović Z, Sedić A. A systematisation of methods for heat integration of solar thermal energy in production processes: A review. J Sustain Dev Energy, Water Environ Syst 2020;8:410–37. doi:10.13044/j.sdewes.d7.0310.
[36] Mazzoni S, Cerri G, Chennaoui L. A simulation tool for concentrated solar power based on micro gas turbine engines. Energy Convers Manag 2018;174:844–54. doi:https://doi.org/10.1016/j.enconman.2018.08.059.
[37] Gambini M, Vellini M. Hybrid thermal power plants: Solar-electricity and fuel-electricity productions. Energy Convers Manag 2019;195:682–9. doi:10.1016/J.ENCONMAN.2019.04.073.
[38] Calise F, d'Accadia MD, Libertini L, Vicidomini M. Thermoeconomic analysis of an integrated solar combined cycle power plant. Energy Convers Manag 2018;171:1038–51. doi:https://doi.org/10.1016/j.enconman.2018.06.005.
[39] Herrando M, Pantaleo AM, Wang K, Markides CN. Solar combined cooling, heating and power systems based on hybrid PVT, PV or solar-thermal collectors for building applications. Renew Energy 2019. doi:10.1016/j.renene.2019.05.004.

[40] Barone G, Buonomano A, Forzano C, Palombo A, Panagopoulos O. Experimentation, modelling and applications of a novel low-cost air-based photovoltaic thermal collector prototype. Energy Convers Manag 2019;195:1079–97. doi:10.1016/J.ENCONMAN.2019.04.082.
[41] Barone G, Buonomano A, Forzano C, Giuzio GF, Palombo A. Passive and active performance assessment of building integrated hybrid solar photovoltaic/thermal collector prototypes: Energy, comfort, and economic analyses. Energy 2020:118435. doi:https://doi.org/10.1016/j.energy.2020.118435.
[42] El Fouas C, Hajji B, Gagliano A, Tina GM, Aneli S. Numerical model and experimental validation of the electrical and thermal performances of photovoltaic/thermal plant. Energy Convers Manag 2020;220:112939. doi:https://doi.org/10.1016/j.enconman.2020.112939.
[43] Ocłoń P, Cisek P, Kozak-Jagieła E, Taler J, Taler D, Skrzyniowska D, et al. Modeling and experimental validation and thermal performance assessment of a sun-tracked and cooled PVT system under low solar irradiation. Energy Convers Manag 2020;222:113289. doi:https://doi.org/10.1016/j.enconman.2020.113289.
[44] Palomba V, Wittstadt U, Bonanno A, Tanne M, Harborth N, Vasta S. Components and design guidelines for solar cooling systems: The experience of ZEOSOL. Renew Energy 2019;141:678–92. doi:10.1016/J.RENENE.2019.04.018.
[45] Alahmer A, Ajib S. Solar cooling technologies: State of art and perspectives. Energy Convers Manag 2020;214:112896. doi:https://doi.org/10.1016/j.enconman.2020.112896.
[46] Calise F, Libertini L, Vicidomini M. Dynamic simulation and thermoeconomic analysis of a novel solar cooling system for a triple-pressure combined cycle power plant. Energy Convers Manag 2018;170:82–96. doi:https://doi.org/10.1016/j.enconman.2018.05.041.
[47] Rosato A, Ciervo A, Ciampi G, Sibilio S. Effects of solar field design on the energy, environmental and economic performance of a solar district heating network serving Italian residential and school buildings. Renew Energy 2019;143:596–610. doi:10.1016/J.RENENE.2019.04.151.
[48] Serale G, Fiorentini M, Capozzoli A, Cooper P, Perino M. Formulation of a model predictive control algorithm to enhance the performance of a latent heat solar thermal system. Energy Convers Manag 2018;173:438–49. doi:https://doi.org/10.1016/j.enconman.2018.07.099.
[49] Buscemi A, Panno D, Ciulla G, Beccali M, Lo Brano V. Concrete thermal energy storage for linear Fresnel collectors: Exploiting the South Mediterranean's solar potential for agri-food processes. Energy Convers Manag 2018;166:719–34. doi:https://doi.org/10.1016/j.enconman.2018.04.075.
[50] Khor J, Yang L, Akhmetov B, Leal A RA. Application of Granular Materials for Void Space Reduction within Packed Bed Thermal Energy Storage System Filled with Macro-Encapsulated Phase Change Materials. Energy Convers Manag n.d.
[51] Nam W, Kim J-Y, Oh K-Y. The characterization of dynamic behavior of Li-ion battery packs for enhanced design and states identification. Energy Convers Manag 2018;162:264–75. doi:https://doi.org/10.1016/j.enconman.2018.02.022.
[52] Boyle J, Littler T, Foley A. Battery energy storage system state-of-charge management to ensure availability of frequency regulating services from wind farms. Renew Energy 2020;160:1119–35. doi:https://doi.org/10.1016/j.renene.2020.06.025.
[53] Steindl G, Kastner W, Stangl V. Comparison of data-driven thermal building models for model predictive control. J Sustain Dev Energy, Water Environ Syst 2019;7:730–42. doi:10.13044/j.sdewes.d7.0286.
[54] Fernández R, Ortiz C, Chacartegui R, Valverde JM, Becerra JA. Dispatchability of solar photovoltaics from thermochemical energy storage. Energy Convers Manag 2019;191:237–46. doi:https://doi.org/10.1016/j.enconman.2019.03.074.
[55] Ancona MA, Antonucci V, Branchini L, Catena F, De Pascale A, Di Blasi A, et al. Thermal integration of a high-temperature co-electrolyzer and experimental methanator for Power-to-

Gas energy storage system. Energy Convers Manag 2019;186:140–55. doi:https://doi.org/10.1016/j.enconman.2019.02.057.
[56] Castellani B, Rinaldi S, Morini E, Nastasi B, Rossi F. Flue gas treatment by power-to-gas integration for methane and ammonia synthesis – Energy and environmental analysis. Energy Convers Manag 2018;171:626–34. doi:https://doi.org/10.1016/j.enconman.2018.06.025.
[57] Chisalita D-A, Petrescu L, Cormos C-C. Environmental evaluation of European ammonia production considering various hydrogen supply chains. Renew Sustain Energy Rev 2020;130:109964. doi:https://doi.org/10.1016/j.rser.2020.109964.
[58] Qian P, Wang J, Wu Z, Yang J, Wang Q. Performance comparison of methane steam reforming in a randomly packed bed and a grille-sphere composite packed bed. Energy Convers Manag 2019;193:39–51. doi:https://doi.org/10.1016/j.enconman.2019.04.052.
[59] Ancona MA, Bianchi M, Branchini L, Catena F, De Pascale A, Melino F, et al. Numerical prediction of off-design performance for a Power-to-Gas system coupled with renewables. Energy Convers Manag 2020;210:112702. doi:https://doi.org/10.1016/j.enconman.2020.112702.
[60] Bhandari R, Sessa V, Adamou R. Rural electrification in Africa – A willingness to pay assessment in Niger. Renew Energy 2020;161:20–9. doi:https://doi.org/10.1016/j.renene.2020.06.151.
[61] Galic M, Bilandzija D, Percin A, Sestak I, Mesic M, Blazinkov M, et al. Effects of agricultural practices on carbon emission and soil health. J Sustain Dev Energy, Water Environ Syst 2019;7:539–52. doi:10.13044/j.sdewes.d7.0271.
[62] Kovačević Markov K, Rajaković N. Multi-energy microgrids with ecotourism purposes: The impact of the power market and the connection line. Energy Convers Manag 2019;196:1105–12. doi:https://doi.org/10.1016/j.enconman.2019.05.048.
[63] Fichera A, Pluchino A, Volpe R. From self-consumption to decentralized distribution among prosumers: A model including technological, operational and spatial issues. Energy Convers Manag 2020;217:112932. doi:https://doi.org/10.1016/j.enconman.2020.112932.
[64] Thellufsen JZ, Lund H, Sorknæs P, Østergaard PA, Chang M, Drysdale D, et al. Smart energy cities in a 100% renewable energy context. Renew Sustain Energy Rev 2020;129:109922. doi:https://doi.org/10.1016/j.rser.2020.109922.
[65] Möller B, Wiechers E, Persson U, Grundahl L, Lund RS, Mathiesen BV. Heat Roadmap Europe: Towards EU-Wide, local heat supply strategies. Energy 2019;177:554–64. doi:10.1016/J.ENERGY.2019.04.098.
[66] Kılkış Ş. Composite index for benchmarking local energy systems of Mediterranean port cities. Energy 2015;92:622–38. doi:10.1016/J.ENERGY.2015.06.093.
[67] Kilkiş Ş. Sustainable development of energy, water and environment systems index for Southeast European cities. J Clean Prod 2016;130:222–34. doi:10.1016/j.jclepro.2015.07.121.
[68] Kilkiş Ş. Benchmarking South East European Cities with the Sustainable Development of Energy, Water and Environment Systems Index. J Sustain Dev Energy, Water Environ Syst 2018;6:162–209. doi:doi.org/10.13044/j.sdewes.d5.0179.
[69] Kilkiş Ş. Application of the Sustainable Development of Energy, Water and Environment Systems Index to World Cities with a Normative Scenario for Rio de Janeiro. J Sustain Dev Energy, Water Environ Syst 2018;6:559–608. doi:10.13044/j.sdewes.d6.0213.
[70] Kılkış Ş. Data on cities that are benchmarked with the sustainable development of energy, water and environment systems index and related cross-sectoral scenario. Data Br 2019;24:103856. doi:10.1016/j.dib.2019.103856.
[71] Kılkış Ş. Benchmarking the sustainability of urban energy, water and environment systems and envisioning a cross-sectoral scenario for the future. Renew Sustain Energy Rev 2019;103:529–45. doi:10.1016/j.rser.2018.11.006.
[72] Aste N, Caputo P, Del Pero C, Ferla G, Huerto-Cardenas HE, Leonforte F, et al. A renewable energy

scenario for a new low carbon settlement in northern Italy: Biomass district heating coupled with heat pump and solar photovoltaic system. Energy 2020;206:118091. doi:10.1016/j.energy.2020.118091.
[73] Kilkiş Ş. Energy system analysis of a pilot net-zero exergy district. Energy Convers Manag 2014;87. doi:10.1016/j.enconman.2014.05.014.
[74] Kilkiş Ş. Exergy transition planning for net-zero districts. Energy 2015;92. doi:10.1016/j.energy.2015.02.009.
[75] Kılkış Ş. A nearly net-zero exergy district as a model for smarter energy systems in the context of urban metabolism. J Sustain Dev Energy, Water Environ Syst 2017;5:101–26. doi:10.13044/j.sdewes.d5.0136.
[76] Kılkış Ş, Kılkış B. An urbanization algorithm for districts with minimized emissions based on urban planning and embodied energy towards net-zero exergy targets. Energy 2019;179:392–406. doi:10.1016/j.energy.2019.04.065.
[77] Ferrari S, Zagarella F, Caputo P, Bonomolo M. Assessment of tools for urban energy planning. Energy 2019;176:544–51. doi:10.1016/j.energy.2019.04.054.
[78] Marrasso E, Roselli C, Sasso M, Picallo-Perez A, Sala Lizarraga JM. Dynamic simulation of a microcogeneration system in a Spanish cold climate. Energy Convers Manag 2018;165:206–18. doi:https://doi.org/10.1016/j.enconman.2018.03.052.
[79] Tian X, You F. Carbon-neutral hybrid energy systems with deep water source cooling, biomass heating, and geothermal heat and power. Appl Energy 2019:413–32. doi:10.1016/j.apenergy.2019.04.172.
[80] Roselli C, Sasso M, Tariello F. Integration of a PV system with an electric heat pump and an electric storage to increase self-consumption of an office building. J Sustain Dev Energy, Water Environ Syst 2019;7:213–28. doi:10.13044/J.SDEWES.D6.0248.
[81] Bellocchi S, Manno M, Noussan M, Prina MG, Vellini M. Electrification of transport and residential heating sectors in support of renewable penetration: Scenarios for the Italian energy system. Energy 2020;196:117062. doi:10.1016/j.energy.2020.117062.
[82] Buonomano A, Calise F, Cappiello FL, Palombo A, Vicidomini M. Dynamic analysis of the integration of electric vehicles in efficient buildings fed by renewables. Appl Energy 2019:31–50. doi:10.1016/j.apenergy.2019.03.206.
[83] Attia H, Mohsen M, Qadoor B, Al Shamsi M, Abdulsalam O, Rahman Z. New Design and Implementation of a Solar Car of the American University of Ras Al Khaimah: Electrical Vision. J Sustain Dev Energy, Water Environ Syst 2020;8:452–63. doi:10.13044/j.sdewes.d7.0281.
[84] Cipek M, Kasać J, Pavković D, Zorc D. A novel cascade approach to control variables optimisation for advanced series-parallel hybrid electric vehicle power-train. Appl Energy 2020;276:115488. doi:https://doi.org/10.1016/j.apenergy.2020.115488.
[85] Ajanovic A, Haas R. On the environmental benignity of electric vehicles. J Sustain Dev Energy, Water Environ Syst 2019;7:416–31. doi:10.13044/j.sdewes.d6.0252.
[86] Thomassen G, Van Passel S, Dewulf J. A review on learning effects in prospective technology assessment. Renew Sustain Energy Rev 2020;130:109937. doi:https://doi.org/10.1016/j.rser.2020.109937.
[87] Al kez D, Foley AM, McIlwaine N, Morrow DJ, Hayes BP, Zehir MA, et al. A critical evaluation of grid stability and codes, energy storage and smart loads in power systems with wind generation. Energy 2020;205:117671. doi:10.1016/j.energy.2020.117671.
[88] Brandoni C, Shah NN, Vorushylo I, Hewitt NJ. Poly-generation as a solution to address the energy challenge of an aging population. Energy Convers Manag 2018;171:635–46. doi:10.1016/j.enconman.2018.06.019.
[89] Lekavičius V, Bobinaitė V, Galinis A, Pažėraitė A. Distributional impacts of investment subsidies

for residential energy technologies. Renew Sustain Energy Rev 2020;130:109961. doi:https://doi.org/10.1016/j.rser.2020.109961.
[90] De Masi RF, de Rossi F, Ruggiero S, Vanoli GP. Numerical optimization for the design of living walls in the Mediterranean climate. Energy Convers Manag 2019;195:573–86. doi:10.1016/J.ENCONMAN.2019.05.043.
[91] Beccali M, Bonomolo M, Lo Brano V, Ciulla G, Di Dio V, Massaro F, et al. Energy saving and user satisfaction for a new advanced public lighting system. Energy Convers Manag 2019;195:943–57. doi:10.1016/J.ENCONMAN.2019.05.070.
[92] Visa I, Moldovan M, Duta A. Experimental Performance Assessment of Vertically Installed Solar Thermal Collectors. J Sustain Dev Energy, Water Environ Syst 2020;8:692–700. doi:10.13044/j.sdewes.d7.0287.
[93] Kareim AA, Mansor M Bin. Support vector machine for MPPT efficiency improvement in photovoltaic system. Int Rev Autom Control 2013;6:177–82. doi:10.15866/ireaco.v6i2.4038.
[94] Calise F, Cappiello FL, Dentice d'Accadia M, Vicidomini M. Dynamic modelling and thermoeconomic analysis of micro wind turbines and building integrated photovoltaic panels. Renew Energy 2020;160:633–52. doi:https://doi.org/10.1016/j.renene.2020.06.075.
[95] Calise F, Cappiello FL, Dentice d'Accadia M, Vicidomini M. Energy efficiency in small districts: Dynamic simulation and technoeconomic analysis. Energy Convers Manag 2020;220:113022. doi:https://doi.org/10.1016/j.enconman.2020.113022.
[96] Lund H, Werner S, Wiltshire R, Svendsen S, Thorsen JE, Hvelplund F, et al. 4th Generation District Heating (4GDH). Integrating smart thermal grids into future sustainable energy systems. Energy 2014;68:1–11. doi:10.1016/j.energy.2014.02.089.
[97] Dorotić H, Pukšec T, Duić N. Economical, environmental and exergetic multi-objective optimization of district heating systems on hourly level for a whole year. Appl Energy 2019;251:113394. doi:https://doi.org/10.1016/j.apenergy.2019.113394.
[98] Doračić B, Pukšec T, Schneider DR, Duić N. The effect of different parameters of the excess heat source on the levelized cost of excess heat. Energy 2020;201:117686. doi:10.1016/j.energy.2020.117686.
[99] Kazagic A, Merzic A, Redzic E, Tresnjo D. Optimization of modular district heating solution based on CHP and RES - Demonstration case of the Municipality of Visoko. Energy 2019;181:56–65. doi:10.1016/j.energy.2019.05.132.
[100] Pieper H, Ommen T, Elmegaard B, Brix Markussen W. Assessment of a combination of three heat sources for heat pumps to supply district heating. Energy 2019;176:156–70. doi:10.1016/j.energy.2019.03.165.
[101] Djørup S, Sperling K, Østergaard PA. District Heating Tariffs, Economic Optimisation and Local Strategies during Radical Technological Change. Energies 2020;13:1172. doi:doi:10.3390/en13051172.
[102] Askeland K, Bozhkova KN, Sorknæs P. Balancing Europe: Can district heating affect the flexibility potential of Norwegian hydropower resources? Renew Energy 2019;141:646–56. doi:10.1016/j.renene.2019.03.137.
[103] Aunedi M, Pantaleo AM, Kuriyan K, Strbac G, Shah N. Modelling of national and local interactions between heat and electricity networks in low-carbon energy systems. Appl Energy 2020;276:115522. doi:https://doi.org/10.1016/j.apenergy.2020.115522.
[104] Moser S, Puschnigg S, Rodin V. Designing the Heat Merit Order to determine the value of industrial waste heat for district heating systems. Energy 2020;200:117579. doi:10.1016/j.energy.2020.117579.
[105] Laine J, Kontu K, Heinonen J, Junnila S. Uncertain greenhouse gas implication in waste heat utilization – A case study with a data center. J Sustain Dev Energy, Water Environ Syst

2020;8:360–72. doi:10.13044/j.sdewes.d7.0301.
[106] Østergaard PA, Jantzen J, Marczinkowski HM, Kristensen M. Business and socioeconomic assessment of introducing heat pumps with heat storage in small-scale district heating systems. Renew Energy 2019;139:904–14. doi:10.1016/j.renene.2019.02.140.
[107] Nguyen T, Gustavsson L. Production of district heat, electricity and/or biomotor fuels in renewable-based energy systems. Energy 2020;202:117672. doi:10.1016/j.energy.2020.117672.
[108] Bozhikaliev V, Sazdovski I, Adler J, Markovska N. Techno-economic, social and environmental assessment of biomass based district heating in a Bioenergy village. J Sustain Dev Energy, Water Environ Syst 2019;7:601–14. doi:10.13044/j.sdewes.d7.0257.
[109] Barone G, Buonomano A, Forzano C, Palombo A. A novel dynamic simulation model for the thermo-economic analysis and optimisation of district heating systems. Energy Convers Manag 2020;220:113052. doi:https://doi.org/10.1016/j.enconman.2020.113052.
[110] Dominković DF, Krajačić G. District cooling versus individual cooling in urban energy systems: The impact of district energy share in cities on the optimal storage sizing. Energies 2019;12. doi:10.3390/en12030407.
[111] Dominković DF, Dobravec V, Jiang Y, Nielsen PS, Krajačić G. Modelling smart energy systems in tropical regions. Energy 2018;155:592–609. doi:doi.org/10.1016/j.energy.2018.05.007.
[112] von Rhein J, Henze GP, Long N, Fu Y. Development of a topology analysis tool for fifth-generation district heating and cooling networks. Energy Convers Manag 2019;196:705–16. doi:https://doi.org/10.1016/j.enconman.2019.05.066.
[113] Allen A, Henze G, Baker K, Pavlak G. Evaluation of low-exergy heating and cooling systems and topology optimization for deep energy savings at the urban district level. Energy Convers Manag 2020;222:113106. doi:https://doi.org/10.1016/j.enconman.2020.113106.
[114] Osman K, Jankovich D. A Unified Approach in System Architecture Development during Energy Efficient Design of Cooling Plants. J Sustain Dev Energy, Water Environ Syst 2020;8:604–21. doi:10.13044/j.sdewes.d7.0318.
[115] Kilkis B. Exergy-Optimum Coupling of Heat Recovery Ventilation Units with Heat Pumps in Sustainable Buildings. J Sustain Dev Energy, Water Environ Syst 2020;8:815–45. doi:10.13044/j.sdewes.d7.0316.
[116] Al Quabeh H, Saab R, Ali MIH. Chilled water storage feasibility with district cooling chiller in tropical environment. J Sustain Dev Energy, Water Environ Syst 2020;8:132–44. doi:10.13044/j.sdewes.d7.0259.
[117] Tawalbeh M, Salameh T, Albawab M, Al-Othman A, El Haj Assad M, Alami AH. Parametric Study of a Single Effect Lithium Bromide-Water Absorption Chiller Powered by a Renewable Heat Source. J Sustain Dev Energy, Water Environ Syst 2020;8:464–75. doi:10.13044/j.sdewes.d7.0290.
[118] Zabala L, Febres J, Sterling R, López S, Keane M. Virtual testbed for model predictive control development in district cooling systems. Renew Sustain Energy Rev 2020;129:109920. doi:https://doi.org/10.1016/j.rser.2020.109920.
[119] Catrini P, Piacentino A, Cardona F, Ciulla G. Exergoeconomic analysis as support in decision-making for the design and operation of multiple chiller systems in air conditioning applications. Energy Convers Manag 2020;220:113051. doi:https://doi.org/10.1016/j.enconman.2020.113051.
[120] Calautit JK, Tien PW, Wei S, Calautit K, Hughes B. Numerical and experimental investigation of the indoor air quality and thermal comfort performance of a low energy cooling windcatcher with heat pipes and extended surfaces. Renew Energy 2020;145:744–56. doi:10.1016/j.renene.2019.06.040.
[121] Ayikoe Tettey UY, Gustavsson L. Energy savings and overheating risk of deep energy renovation of a multi-storey residential building in a cold climate under climate change. Energy 2020;202:117578. doi:10.1016/j.energy.2020.117578.

[122] Meschede H. Increased utilisation of renewable energies through demand response in the water supply sector – A case study. Energy 2019;175:810–7. doi:10.1016/J.ENERGY.2019.03.137.
[123] Di Fraia S, Massarotti N, Vanoli L. A novel energy assessment of urban wastewater treatment plants. Energy Convers Manag 2018;163:304–13. doi:10.1016/j.enconman.2018.02.058.
[124] Curto D, FRANZITTA V, Trapanese M, Cirrincione M. A Preliminary Energy Assessment to Improve the Energy Sustainability in the Small Islands of the Mediterranean Sea. J Sustain Dev Energy, Water Environ Syst 2020;8:735–53. doi:10.13044/j.sdewes.d7.0314.
[125] Pustina L, Lugni C, Bernardini G, Serafini J, Gennaretti M. Control of power generated by a floating offshore wind turbine perturbed by sea waves. Renew Sustain Energy Rev 2020;132:109984. doi:https://doi.org/10.1016/j.rser.2020.109984.
[126] Pantua CAJ, Calautit JK, Wu Y. A fluid-structure interaction (FSI) and energy generation modelling for roof mounted renewable energy installations in buildings for extreme weather and typhoon resilience. Renew Energy 2020;160:770–87. doi:https://doi.org/10.1016/j.renene.2020.06.023.
[127] Rusu L. A projection of the expected wave power in the Black Sea until the end of the 21st century. Renew Energy 2020;160:136–47. doi:https://doi.org/10.1016/j.renene.2020.06.092.
[128] Rusu E. An evaluation of the wind energy dynamics in the Baltic Sea, past and future projections. Renew Energy 2020;160:350–62. doi:https://doi.org/10.1016/j.renene.2020.06.152.
[129] Vaz JRP, Mesquita ALA, Amarante Mesquita AL, Oliveira TF de, Brasil Junior ACP. Powertrain assessment of wind and hydrokinetic turbines with diffusers. Energy Convers Manag 2019;195:1012–21. doi:10.1016/J.ENCONMAN.2019.05.050.
[130] Pavković D, Cipek M, Hrgetić M, Sedić A. Modeling, parameterization and damping optimum-based control system design for an airborne wind energy ground station power plant. Energy Convers Manag 2018;164:262–76. doi:https://doi.org/10.1016/j.enconman.2018.02.090.
[131] Johnston B, Foley A, Doran J, Littler T. Levelised cost of energy, A challenge for offshore wind. Renew Energy 2020;160:876–85. doi:https://doi.org/10.1016/j.renene.2020.06.030.
[132] Majidi Nezhad M, Heydari A, Groppi D, Cumo F, Astiaso Garcia D. Wind source potential assessment using Sentinel 1 satellite and a new forecasting model based on machine learning: A case study Sardinia islands. Renew Energy 2020;155:212–24. doi:https://doi.org/10.1016/j.renene.2020.03.148.
[133] Di Fraia S, Figaj RD, Massarotti N, Vanoli L. An integrated system for sewage sludge drying through solar energy and a combined heat and power unit fuelled by biogas. Energy Convers Manag 2018;171:587–603. doi:https://doi.org/10.1016/j.enconman.2018.06.018.
[134] Di Fraia S, Macaluso A, Massarotti N, Vanoli L. Energy, exergy and economic analysis of a novel geothermal energy system for wastewater and sludge treatment. Energy Convers Manag 2019;195:533–47. doi:10.1016/J.ENCONMAN.2019.05.035.
[135] Metolina P, Lopes GC. Numerical analysis of liquid-solid flow in tapered and cylindrical fluidized beds for wastewater treatment and biogas production. Energy Convers Manag 2019;187:447–58. doi:https://doi.org/10.1016/j.enconman.2019.02.092.
[136] Di Fraia S, Macaluso A, Massarotti N VL. Geothermal energy for wastewater and sludge treatment: an exergoeconomic analysis. Energy Convers Manag n.d.
[137] Gil-Carrera L, Pelaz G, Mateos R, Escapa A. Estimating the Carbon Footprint of Microbial Electrolysis Cells in Wastewater Treatment Plants: Case Study. J Sustain Dev Energy, Water Environ Syst 2020;8:537–46. doi:10.13044/j.sdewes.d7.0296.
[138] Grosser A, Neczaj E, Jasinska A, Celary P. The influence of grease trap sludge sterilization on the performance of anaerobic co-digestion of sewage sludge. Renew Energy 2020;161:988–97. doi:https://doi.org/10.1016/j.renene.2020.07.108.
[139] Di Fraia S, Massarotti N, Prati M V, Vanoli L. A new example of circular economy: Waste vegetable oil for cogeneration in wastewater treatment plants. Energy Convers Manag

2020;211:112763. doi:https://doi.org/10.1016/j.enconman.2020.112763.
[140] Calise F, Cappiello FL, Vanoli R, Vicidomini M. Economic assessment of renewable energy systems integrating photovoltaic panels, seawater desalination and water storage. Appl Energy 2019;253:113575. doi:10.1016/j.apenergy.2019.113575.
[141] Calise F, Dentice d'Accadia M, Vicidomini M. Optimization and dynamic analysis of a novel polygeneration system producing heat, cool and fresh water. Renew Energy 2019;143:1331–47. doi:10.1016/J.RENENE.2019.05.051.
[142] Uche J, Muzás A, Acevedo LE, Usón S, Martínez A, Bayod AA. Experimental tests to validate the simulation model of a Domestic Trigeneration Scheme with hybrid RESs and Desalting Techniques. Renew Energy 2020;155:407–19. doi:10.1016/j.renene.2020.03.147.
[143] Campione A, Cipollina A, Calise F, Tamburini A, Galluzzo M, Micale G. Coupling electrodialysis desalination with photovoltaic and wind energy systems for energy storage: Dynamic simulations and control strategy. Energy Convers Manag 2020;216:112940. doi:10.1016/j.enconman.2020.112940.
[144] Giacalone F, Vassallo F, Griffin L, Ferrari MC, Micale G, Scargiali F, et al. Thermolytic reverse electrodialysis heat engine: model development, integration and performance analysis. Energy Convers Manag 2019;189:1–13. doi:10.1016/j.enconman.2019.03.045.
[145] Giacalone F, Catrini P, Tamburini A, Cipollina A, Piacentino A, Micale G. Exergy analysis of reverse electrodialysis. Energy Convers Manag 2018;164:588–602. doi:https://doi.org/10.1016/j.enconman.2018.03.014.
[146] Ortega-Delgado B, Giacalone F, Catrini P, Cipollina A, Piacentino A, Tamburini A, et al. Reverse electrodialysis heat engine with multi-effect distillation: Exergy analysis and perspectives. Energy Convers Manag 2019;194:140–59. doi:10.1016/j.enconman.2019.04.056.
[147] Altaee A, Cippolina A. Modelling and optimization of modular system for power generation from a salinity gradient. Renew Energy 2019;141:139–47. doi:10.1016/j.renene.2019.03.138.
[148] Safder U, Ifaei P, Yoo C. A novel approach for optimal energy recovery using pressure retarded osmosis technology: Chemical exergy pinch analysis – Case study in a sugar mill plant. Energy Convers Manag 2020;213:112810. doi:https://doi.org/10.1016/j.enconman.2020.112810.
[149] Barone G, Buonomano A, Forzano C, Palombo A, Vicidomini M. Sustainable energy design of cruise ships through dynamic simulations: Multi-objective optimization for waste heat recovery. Energy Convers Manag 2020;221:113166. doi:10.1016/j.enconman.2020.113166.
[150] Barsi D, Costa C, Satta F, Zunino P, Busi A, Ghio R, et al. Design of a mini combined heat and power cycle for naval applications. J Sustain Dev Energy, Water Environ Syst 2020;8:281–92. doi:10.13044/j.sdewes.d7.0309.
[151] Degiuli N, Martić I, Farkas A. Environmental aspects of total resistance of container ship in the north atlantic. J Sustain Dev Energy, Water Environ Syst 2019;7:641–55. doi:10.13044/j.sdewes.d7.0267.
[152] Holik M, Živić M, Virag Z, Barac A. Optimization of an organic Rankine cycle constrained by the application of compact heat exchangers. Energy Convers Manag 2019;188:333–45. doi:https://doi.org/10.1016/j.enconman.2019.03.039.
[153] Zou H, Han X, Huang G, Chen Y, Tian C. Analysis of optimal injection ratio of vapor injection heat pump for electric railway vehicles. J Sustain Dev Energy, Water Environ Syst 2019;7:656–66. doi:10.13044/j.sdewes.d7.0280.
[154] Varga Z, Csaba T. Techno-economic evaluation of waste heat recovery by organic Rankine cycle using pure light hydrocarbons and their mixtures as working fluid in a crude oil refinery. Energy Convers Manag 2018;174:793–801. doi:https://doi.org/10.1016/j.enconman.2018.08.031.
[155] Villarini M, Tascioni R, Arteconi A, Cioccolanti L. Influence of the incident radiation on the energy performance of two small-scale solar Organic Rankine Cycle trigenerative systems: A simulation

analysis. Appl Energy 2019;242:1176–88. doi:https://doi.org/10.1016/j.apenergy.2019.03.066.

[156] Hossin K, Mahkamov K, Belgasim B. Thermodynamic Analysis and Sizing of a Small Scale Solar Thermal Power System Based on Organic Rankine Cycle. J Sustain Dev Energy, Water Environ Syst 2020;8:493–506. doi:10.13044/j.sdewes.d7.0294.

[157] Anastasovski A, Rasković P, Guzović Z. A review of heat integration approaches for organic rankine cycle with waste heat in production processes. Energy Convers Manag 2020;221:113175. doi:https://doi.org/10.1016/j.enconman.2020.113175.

[158] Talent M. Smarter cities: Cleaning electricity, gas and water metered consumption data for social and urban research. J Sustain Dev Energy, Water Environ Syst 2019;7:466–81. doi:10.13044/j.sdewes.d6.0242.

[159] Gianniou P, Liu X, Heller A, Nielsen PS, Rode C. Clustering-based analysis for residential district heating data. Energy Convers Manag 2018;165:840–50. doi:10.1016/j.enconman.2018.03.015.

[160] Markovič R, Gosak M, Grubelnik V, Marhl M, Virtič P. Data-driven classification of residential energy consumption patterns by means of functional connectivity networks. Appl Energy 2019:506–15. doi:10.1016/j.apenergy.2019.03.134.

[161] Timur O, Zor K, Çelik Ö, Teke A, İbrikçi T. Application of Statistical and Artificial Intelligence Techniques for Medium-Term Electrical Energy Forecasting: A Case Study for a Regional Hospital. J Sustain Dev Energy, Water Environ Syst 2020;8:520–36. doi:10.13044/j.sdewes.d7.0306.

[162] Wei S, Tien PW, Calautit JK, Wu Y, Boukhanouf R. Vision-based detection and prediction of equipment heat gains in commercial office buildings using a deep learning method. Appl Energy 2020;277:115506. doi:https://doi.org/10.1016/j.apenergy.2020.115506.

[163] Vialetto G, Noro M. An innovative approach to design cogeneration systems based on big data analysis and use of clustering methods. Energy Convers Manag 2020;214:112901. doi:https://doi.org/10.1016/j.enconman.2020.112901.

[164] Panuschka S, Hofmann R. Impact of thermal storage capacity, electricity and emission certificate costs on the optimal operation of an industrial energy system. Energy Convers Manag 2019;185:622–35. doi:https://doi.org/10.1016/j.enconman.2019.02.014.

[165] Ahmed N, Elfeky KE, Lu L, Wang QW. Thermal and economic evaluation of thermocline combined sensible-latent heat thermal energy storage system for medium temperature applications. Energy Convers Manag 2019;189:14–23. doi:https://doi.org/10.1016/j.enconman.2019.03.040.

[166] Ranilović B, Grozdek M. Potential for mitigation of solar collector overheating through application of phase change materials – a review. J Sustain Dev Energy, Water Environ Syst 2017;8:622–40. doi:https://doi.org/10.13044/j.sdewes.d8.0324.

[167] Forzano C, Baggio P, Buonomano A, Palombo A. Building integrating phase change materials: A dynamic hygrothermal simulation model for system analysis. J Sustain Dev Energy, Water Environ Syst 2019;7:325–42. doi:10.13044/j.sdewes.d6.0255.

[168] Xu Z, Li X, Zhu Z, Wang Q, Chen Y, Ma T. Experimental study on the heat transfer performance of a gallium heat sink. Energy Convers Manag 2020;213:112853. doi:https://doi.org/10.1016/j.enconman.2020.112853.

[169] Borjigin S, Zhang S, Ma T, Zeng M, Wang Q. Performance enhancement of cabinet cooling system by utilizing cross-flow plate heat exchanger. Energy Convers Manag 2020;213:112854. doi:https://doi.org/10.1016/j.enconman.2020.112854.

[170] Dongxu J, Zhongbao W, Pou J, Mazzoni S, Rajoo S, Romagnoli A. Geometry optimization of thermoelectric modules: Simulation and experimental study. Energy Convers Manag 2019;195:236–43. doi:10.1016/j.enconman.2019.05.003.

[171] Li X, Deng T, Ma T, Ke H, Wang Q. A new evaluation method for overall heat transfer performance of supercritical carbon dioxide in a printed circuit heat exchanger. Energy Convers Manag 2019;193:99–105. doi:10.1016/j.enconman.2019.04.061.

[172] Katulić S, Čehil M, Schneider DR. Exergoeconomic optimization of a combined cycle power plant's bottoming cycle using organic working fluids. Energy Convers Manag 2018;171:1721–36. doi:https://doi.org/10.1016/j.enconman.2018.06.103.
[173] Li Q, Wang J, Wang J, Baleta J, Min C, Sundén B. Effects of gravity and variable thermal properties on nanofluid convective heat transfer using connected and unconnected walls. Energy Convers Manag 2018;171:1440–8. doi:https://doi.org/10.1016/j.enconman.2018.06.097.
[174] Costa M, Di Blasio G, Prati M V, Costagliola MA, Cirillo D, La Villetta M, et al. Multi-objective optimization of a syngas powered reciprocating engine equipping a combined heat and power unit. Appl Energy 2020;275:115418. doi:https://doi.org/10.1016/j.apenergy.2020.115418.
[175] Božić M, Vučetić A, Sjerić M, Kozarac D, Lulić Z. Experimental study on knock sources in spark ignition engine with exhaust gas recirculation. Energy Convers Manag 2018;165:35–44. doi:https://doi.org/10.1016/j.enconman.2018.03.053.
[176] Petranović Z, Sjerić M, Taritaš I, Vujanović M, Kozarac D. Study of advanced engine operating strategies on a turbocharged diesel engine by using coupled numerical approaches. Energy Convers Manag 2018;171:1–11. doi:https://doi.org/10.1016/j.enconman.2018.05.085.
[177] Jurić F, Petranović Z, Vujanović M, Duić N. Numerical assessment of radiative heat transfer impact on pollutant formation processes in a compression ignition engine. J Clean Prod 2020;275:123087. doi:https://doi.org/10.1016/j.jclepro.2020.123087.
[178] Jurić F, Petranović Z, Vujanović M, Katrašnik T, Vihar R, Wang X, et al. Experimental and numerical investigation of injection timing and rail pressure impact on combustion characteristics of a diesel engine. Energy Convers Manag 2019;185:730–9. doi:https://doi.org/10.1016/j.enconman.2019.02.039.
[179] Wang J, Liu C, Zhao Z, Baleta J, Sundén B. Effect and optimization of backward hole parameters on film cooling performance by Taguchi method. Energy Convers Manag 2020;214:112809. doi:https://doi.org/10.1016/j.enconman.2020.112809.
[180] Zhang X, Hou X, Wang Y, Zhang J. Study on flame characteristics of low heat value gas. Energy Convers Manag 2019;196:344–53. doi:https://doi.org/10.1016/j.enconman.2019.05.024.
[181] Wang Y, Zhang X, Li Y, Qin S. Experimental study on premixed turbulent flame of methane/air in a spherical closed chamber. Energy Convers Manag 2020;222:113219. doi:https://doi.org/10.1016/j.enconman.2020.113219.
[182] Cerinski D, Vujanović M, Petranović Z, Baleta J, Samec N, Hriberšek M. Numerical analysis of fuel injection configuration on nitrogen oxides formation in a jet engine combustion chamber. Energy Convers Manag 2020;220:112862. doi:https://doi.org/10.1016/j.enconman.2020.112862.
[183] Bešenić T, Baleta J, Pachler K, Vujanović M. Numerical modelling of sulfur dioxide absorption for spray scrubbing. Energy Convers Manag 2020;217:112762. doi:https://doi.org/10.1016/j.enconman.2020.112762.
[184] Wang X, Zhang J, Bai S, Zhang L, Li Y, Mikulčić H, et al. Effect of pyrolysis upgrading temperature on particulate matter emissions from lignite semi-char combustion. Energy Convers Manag 2019;195:384–91. doi:10.1016/j.enconman.2019.05.021.
[185] Wang X, Jin Q, Zhang J, Li Y, Li S, Mikulčić H, et al. Soot formation during polyurethane (PU) plastic pyrolysis: The effects of temperature and volatile residence time. Energy Convers Manag 2018;164:353–62. doi:https://doi.org/10.1016/j.enconman.2018.02.082.
[186] Moço A, Costa M, Casaca C. Ash deposit formation during the combustion of pulverized grape pomace in a drop tube furnace. Energy Convers Manag 2018;169:383–9. doi:https://doi.org/10.1016/j.enconman.2018.05.080.
[187] Aghaalikhani A, Schmid JC, Borello D, Fuchs J, Benedikt F, Hofbauer H, et al. Detailed modelling of biomass steam gasification in a dual fluidized bed gasifier with temperature variation. Renew Energy 2019;143:703–18. doi:10.1016/j.renene.2019.05.022.

[188] Hu Z, Wang X, Zhang L, Yang S, Ruan R, Bai S, et al. Emission characteristics of particulate matters from a 30 MW biomass-fired power plant in China. Renew Energy 2020;155:225–36. doi:https://doi.org/10.1016/j.renene.2020.03.094.
[189] La Villetta M, Costa M, Cirillo D, Massarotti N, Vanoli L. Performance analysis of a biomass powered micro-cogeneration system based on gasification and syngas conversion in a reciprocating engine. Energy Convers Manag 2018;175:33–48. doi:https://doi.org/10.1016/j.enconman.2018.08.017.
[190] Sanchez Moore CC, Anton L, Cardoso FH, Kulay L. Effect of process parameters on bioelectricity production, energy and environmental performance. J Sustain Dev Energy, Water Environ Syst 2019;7:567–83. doi:10.13044/j.sdewes.d6.0237.
[191] Corbellini V, Kougias PG, Treu L, Bassani I, Malpei F, Angelidaki I. Hybrid biogas upgrading in a two-stage thermophilic reactor. Energy Convers Manag 2018;168:1–10. doi:https://doi.org/10.1016/j.enconman.2018.04.074.
[192] Stančin H, Mikulčić H, Wang X, Duić N. A review on alternative fuels in future energy system. Renew Sustain Energy Rev 2020;128:109927. doi:https://doi.org/10.1016/j.rser.2020.109927.
[193] Cardona-Alzate CA, Serna-Loaiza S, Ortiz-Sanchez M. Sustainable biorefineries: What was learned from the design, analysis and implementation. J Sustain Dev Energy, Water Environ Syst 2020;8:88–117. doi:10.13044/j.sdewes.d7.0268.
[194] Seljak T, Buffi M, Valera-Medina A, Chong CT, Chiaramonti D, Katrašnik T. Bioliquids and their use in power generation – A technology review. Renew Sustain Energy Rev 2020;129:109930. doi:https://doi.org/10.1016/j.rser.2020.109930.
[195] Cerone N, Zimbardi F, Contuzzi L, Baleta J, Cerinski D, Skvorčinskienė R. Experimental investigation of syngas composition variation along updraft fixed bed gasifier. Energy Convers Manag 2020;221. doi:10.1016/j.enconman.2020.113116.
[196] Zadravec T, Yin C, Kokalj F, Samec N, Rajh B. The impacts of different profiles of the grate inlet conditions on freeboard CFD in a waste wood-fired grate boiler. Appl Energy 2020;268:115055. doi:https://doi.org/10.1016/j.apenergy.2020.115055.
[197] Golub G, Kukharets S, Yarosh Y, Chuba V. Method for optimization of the gasifier recovery zone height. J Sustain Dev Energy, Water Environ Syst 2019;7:493–505. doi:10.13044/j.sdewes.d6.0245.
[198] Mikulandrić R, Böhning D, Lončar D. Modelling of temperature and syngas composition in a fixed bed biomass gasifier using nonlinear autoregressive networks. J Sustain Dev Energy, Water Environ Syst 2020;8:145–61. doi:10.13044/j.sdewes.d7.0263.
[199] Lovrak A, Pukšec T, Duić N. A Geographical Information System (GIS) based approach for assessing the spatial distribution and seasonal variation of biogas production potential from agricultural residues and municipal biowaste. Appl Energy 2020;267:115010. doi:https://doi.org/10.1016/j.apenergy.2020.115010.
[200] Manić NG, Janković BB, Dodevski VM, Stojiljković DD, Jovanović V V. Multicomponent Modelling Kinetics and Simultaneous Thermal Analysis of Apricot Kernel Shell Pyrolysis. J Sustain Dev Energy, Water Environ Syst 2020;8:766–87. doi:10.13044/j.sdewes.d7.0307.
[201] Tomasek S, Lónyi F, Valyon J, Hancsók J. Fuel purpose hydrocracking of biomass based Fischer-Tropsch paraffin mixtures on bifunctional catalysts. Energy Convers Manag 2020;213:112775. doi:https://doi.org/10.1016/j.enconman.2020.112775.
[202] Kim Y-M, Jeong J, Ryu S, Lee HW, Jung JS, Siddiqui MZ, et al. Catalytic pyrolysis of wood polymer composites over hierarchical mesoporous zeolites. Energy Convers Manag 2019;195:727–37. doi:10.1016/J.ENCONMAN.2019.05.034.
[203] Tóth O, Holló A, Hancsók J. Co-processing a waste fatty acid mixture and unrefined gas oil to produce renewable diesel fuel-blending components. Energy Convers Manag 2019;185:304–12.

doi:https://doi.org/10.1016/j.enconman.2019.02.023.
[204] Chen AF, Akmal Adzmi M, Adam A, Othman MF, Kamaruzzaman MK, Mrwan AG. Combustion characteristics, engine performances and emissions of a diesel engine using nanoparticle-diesel fuel blends with aluminium oxide, carbon nanotubes and silicon oxide. Energy Convers Manag 2018;171:461–77. doi:https://doi.org/10.1016/j.enconman.2018.06.004.
[205] Ferla G, Caputo P, Colaninno N, Morello E. Urban greenery management and energy planning: A GIS-based potential evaluation of pruning by-products for energy application for the city of Milan. Renew Energy 2020;160:185–95. doi:https://doi.org/10.1016/j.renene.2020.06.105.
[206] Aberilla JM, Gallego-Schmid A, Azapagic A. Environmental sustainability of small-scale biomass power technologies for agricultural communities in developing countries. Renew Energy 2019;141:493–506. doi:https://doi.org/10.1016/j.renene.2019.04.036.
[207] Jarrar L, Ayadi O, Al Asfar J. Techno-economic Aspects of Electricity Generation from a Farm Based Biogas Plant. J Sustain Dev Energy, Water Environ Syst 2020;8:476–92. doi:10.13044/j.sdewes.d7.0302.
[208] Fan Y Van, Tan RR, Klemeš JJ. A system analysis tool for sustainable biomass utilisation considering the Emissions-Cost Nexus. Energy Convers Manag 2020;210:112701. doi:https://doi.org/10.1016/j.enconman.2020.112701.
[209] Wang X, Zhu Y, Hu Z, Zhang L, Yang S, Ruan R, et al. Characteristics of ash and slag from four biomass-fired power plants: Ash/slag ratio, unburned carbon, leaching of major and trace elements. Energy Convers Manag 2020;214:112897. doi:https://doi.org/10.1016/j.enconman.2020.112897.
[210] Klebson de Medeiros Silva W, Neves TI, de Souza Silva C, Carvalho M, Abrahão R. Sustainable enhancement of sugarcane fertilization for energy purposes in hot climates. Renew Energy 2020;159:547–52. doi:https://doi.org/10.1016/j.renene.2020.05.178.
[211] Codignole Luz F, Cordiner S, Manni A, Mulone V, Rocco V. Biomass fast pyrolysis in screw reactors: Prediction of spent coffee grounds bio-oil production through a monodimensional model. Energy Convers Manag 2018;168:98–106. doi:https://doi.org/10.1016/j.enconman.2018.04.104.
[212] Sedlar DK, Vulin D, Krajačić G, Jukić L. Offshore gas production infrastructure reutilisation for blue energy production. Renew Sustain Energy Rev 2019;108:159–74. doi:10.1016/J.RSER.2019.03.052.
[213] Silva Ortiz P, Flórez-Orrego D, de Oliveira Junior S, Maciel Filho R, Osseweijer P, Posada J. Unit exergy cost and specific CO2 emissions of the electricity generation in the Netherlands. Energy 2020;208:118279. doi:https://doi.org/10.1016/j.energy.2020.118279.
[214] Khor JO, Dal Magro F, Gundersen T, Sze JY, Romagnoli A. Recovery of cold energy from liquefied natural gas regasification: Applications beyond power cycles. Energy Convers Manag 2018;174:336–55. doi:10.1016/j.enconman.2018.08.028.
[215] Interlenghi SF, Silva R de PF, de Medeiros JL, Araújo O de QF. Low-emission offshore Gas-To-Wire from natural gas with carbon dioxide: Supersonic separator conditioning and post-combustion decarbonation. Energy Convers Manag 2019;195:1334–49. doi:https://doi.org/10.1016/j.enconman.2019.05.096.
[216] Interlenghi SF, de Medeiros JL, Araújo O de QF. On small-scale liquefaction of natural gas with supersonic separator: Energy and second law analyses. Energy Convers Manag 2020;221:113117. doi:https://doi.org/10.1016/j.enconman.2020.113117.
[217] Jovanović R, Swiatkowski B, Kakietek S, Škobalj P, Lazović I, Cvetinović D. Mathematical modelling of swirl oxy-fuel burner flame characteristics. Energy Convers Manag 2019;191:193–207. doi:https://doi.org/10.1016/j.enconman.2019.04.027.
[218] Brigagão GV, de Medeiros JL, Araújo O de QF. A novel cryogenic vapor-recompression air

separation unit integrated to oxyfuel combined-cycle gas-to-wire plant with carbon dioxide enhanced oil recovery: Energy and economic assessments. Energy Convers Manag 2019;189:202–14. doi:https://doi.org/10.1016/j.enconman.2019.03.088.
[219] Poblete IBS, Araujo O de QF, de Medeiros JL. Dynamic analysis of sustainable biogas-combined-cycle plant: Time-varying demand and bioenergy with carbon capture and storage. Renew Sustain Energy Rev 2020;131:109997. doi:https://doi.org/10.1016/j.rser.2020.109997.
[220] Carminati HB, Milão R de FD, de Medeiros JL, Araújo O de QF. Bioenergy and full carbon dioxide sinking in sugarcane-biorefinery with post-combustion capture and storage: Techno-economic feasibility. Appl Energy 2019;254:113633. doi:10.1016/j.apenergy.2019.113633.
[221] Lin WY, Li T, Akasyah L, Lim JWM, Xu H, Py X, et al. Comparison of sintering condition and radio frequency plasma discharge on the conversion of coal/biomass fly ash into high-temperature thermal energy storage material. Energy Convers Manag 2019;192:180–7. doi:10.1016/j.enconman.2019.03.076.
[222] Pacheco KA, Bresciani AE, Nascimento CAO, Alves RMB. Assessment of property estimation methods for the thermodynamics of carbon dioxide-based products. Energy Convers Manag 2020;211:112756. doi:https://doi.org/10.1016/j.enconman.2020.112756.
[223] Breyer C. Impact of the Transition Towards 100% Renewable Energy Systems on Primary and Final Energy Demand 2019. https://www.dubrovnik2019.sdewes.org/lectures.php.
[224] Bogdanov D, Farfan J, Sadovskaia K, Aghahosseini A, Child M, Gulagi A, et al. Radical transformation pathway towards sustainable electricity via evolutionary steps. Nat Commun 2019;10:1–16. doi:10.1038/s41467-019-08855-1.
[225] Child M, Kemfert C, Bogdanov D, Breyer C. Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe. Renew Energy 2019;139:80–101. doi:https://doi.org/10.1016/j.renene.2019.02.077.
[226] Aghahosseini A, Bogdanov D, Barbosa LSNS, Breyer C. Analysing the feasibility of powering the Americas with renewable energy and inter-regional grid interconnections by 2030. Renew Sustain Energy Rev 2019;105:187–205. doi:https://doi.org/10.1016/j.rser.2019.01.046.
[227] Aghahosseini A, Bogdanov D, Breyer C. Towards sustainable development in the MENA region: Analysing the feasibility of a 100% renewable electricity system in 2030. Energy Strateg Rev 2020;28:100466. doi:https://doi.org/10.1016/j.esr.2020.100466.
[228] Ram M, Aghahosseini A, Breyer C. Job creation during the global energy transition towards 100% renewable power system by 2050. Technol Forecast Soc Change 2020;151:119682. doi:https://doi.org/10.1016/j.techfore.2019.06.008.
[229] Hansen K, Breyer C, Lund H. Status and perspectives on 100% renewable energy systems. Energy 2019;175:471–80. doi:https://doi.org/10.1016/j.energy.2019.03.092.
[230] Lund H. 100% Renewable Smart Energy Systems 2019. https://www.dubrovnik2019.sdewes.org/lectures.php.
[231] Smith R. Rethinking Future Industrial Energy Systems 2019. https://www.dubrovnik2019.sdewes.org/lectures.php.