




Review

# Recent Advances in the Analysis of Sustainable Energy Systems

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**Abstract:** EU energy policy is more and more promoting a resilient, efficient and sustainable energy system. Several agreements have been signed in the last few months that set ambitious goals in terms of energy efficiency and emission reductions and to reduce the energy consumption in buildings. These actions are expected to fulfill the goals negotiated at the Paris Agreement in 2015. The successful development of this ambitious energy policy needs to be supported by scientific knowledge: a huge effort must be made in order to develop more efficient energy conversion technologies based both on renewables and fossil fuels. Similarly, researchers are also expected to work on the integration of conventional and novel systems, also taking into account the needs for the management of the novel energy systems in terms of energy storage and devices management. Therefore, a multi-disciplinary approach is required in order to achieve these goals. To ensure that the scientists belonging to the different disciplines are aware of the scientific progress in the other research areas, specific Conferences are periodically organized. One of the most popular conferences in this area is the Sustainable Development of Energy, Water and Environment Systems (SDEWES) Series Conference. The 12th Sustainable Development of Energy, Water and Environment Systems Conference was recently held in Dubrovnik, Croatia. The present Special Issue of *Energies*, specifically dedicated to the 12th SDEWES Conference, is focused on five main fields: energy policy and energy efficiency in smart energy systems, polygeneration and district heating, advanced combustion techniques and fuels, biomass and building efficiency.

**Keywords:** renewable energy; smart cities; district heating and cooling; sustainable development

## 1. Introduction

On 18 June 2018 a new agreement, dealing with EU energy policy, was reached between negotiators from the EU Parliament, Commission and Council. This agreement will promote the development of a reliable and environmental friendly energy system for the countries of the European Union. This legislative proposal is included in the Clean Energy for All Europeans package presented by the European Commission on November 2016. The previous proposals were negotiated on the revised Renewable Energy Directive and on the Energy Performance in Buildings Directive. This new agreement includes extremely ambitious targets in terms of energy efficiency: 32.5% for 2030 with

an upwards revision clause by 2023. Similarly, a target of 40% in terms of reduction of emissions was also agreed. These targets, combined with 32% renewable energy target for the EU for 2030 (see STATEMENT/18/4155) and the revision of Energy Building Performance Directive, will allow Europe to achieve the goals established by the Paris Agreement in order to complete the transition towards a clean energy system. In addition, EU citizens may benefit from a more efficient energy market, where a substantial reduction in energy bills will be achieved, along with an improved security of the energy supply systems and a more comfortable and healthy environment [1].

These ambitious goals require a huge effort by industry and academia in order to design and analyze novel energy conversion systems and the integration of renewables in conventional energy systems [2]. In particular, several researchers have been involved in this area [3], analyzing energy, environmental and economic aspects of sustainable development initiatives [4], promoting and disseminating the results of their research [5] and developing novel solutions for specific sectors [6–9]. Sustainable development is a highly interdisciplinary concept, involving a number of different disciplines (energy, water, renewable, electrical engineering, control engineering, etc.). To analyze these topics, a couple of decades ago, the Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conference series was initiated.

In 2017, the 12th SDEWES Conference (SDEWES 2017) was held in Dubrovnik, Croatia. The Conference was attended by 530 researchers coming from around 60 countries. The Conference also included 12 special sessions, two special events, four invited lectures and two panels by some of the most eminent experts in the field. A total of 450 papers and 100 posters were presented.

The papers in this Special Issue (SI) are selected among the works presented at the SDEWES 2017 Conference. The conference covered a plurality of research fields and skills. Papers included technical, economic, environmental and social analyses aiming to develop sustainable energy, transport and water systems. From among the 450 accepted manuscripts, 17 were selected for this special issue of *Energies*. The present paper aims to provide an overview of the papers included in the abovementioned special issue. In addition, this paper also includes a comprehensive literature review presenting the works previously published in past SDEWES special Issues, dealing with the same topics addressed in the present SI. This literature review is intended to provide an overview of the development of the research performed by the scientists participating to the SDEWES conferences in order to highlight the recent progress of the research in these fields.

This is the first cooperation between *Energies* and SDEWES which will be certainly continued due to the success of the present special issue. The papers within the present special issue can be classified into five main research fields. These research fields are: energy policy and energy efficiency in smart energy systems (three papers), polygeneration and district heating (three papers), advanced combustion techniques and fuels (two papers), biomass (two papers) and building efficiency (four papers). Three additional papers deal with other miscellaneous topics related to this special issue.

## 2. Background

This section presents a review of the papers previously published in journals' special issues dedicated to past SDEWES conferences. The papers here analyzed can be classified into the five research fields mentioned before.

### 2.1. Energy Policy and Energy Efficiency in Smart Energy Systems

The topic of the development of a novel and sustainable energy system, especially at the urban level, was widely investigated during previous SDEWES conferences. Dozens of papers are available in the various previous SDEWES special issues regarding this topic, using a plurality of different approaches [10,11]. The following Table 1 summarizes the papers analyzed in this subsection, showing the methodologies, topics and main findings.

**Table 1.** Main topics, methodologies and outcomes of the previous SDEWES papers dealing with energy policy and energy efficiency in smart energy systems.

Reference	Topic	Methodology	Main Outcomes
[12]	Energy security	Numerical model	Energy Security indicators
[13]	Energy security	Geo-economic model	Geo-economic Index of Energy Security
[14]	Energy poverty	Analytical Hierarchy Process	Multi-Criteria Decision Analysis
[15]	Energy poverty	Analytical Model	Multidimensional energy poverty index (MEPI),
[16]	Socio-technical optimality	Conceptual model	Conceptual model
[17]	Sustainable urban mobility plans	mutual learning workshop	Workshops
[18]	GHG emission reduction	ALTER-MOTIVE model	Policy scenario
[19]	Electric Vehicles	Numerical model	Promotional policies
[20]	Sustainable Transportation	Numerical model	Alternatives to the current fossil fuel systems
[21]	Hydrogen transportation	Numerical model	Design of the hydrogen infrastructure in Croatia
[22]	Sustainable mobility	Environmental Impact Study	A case study for Macchia Lucchese
[23]	Energy efficiency in the EU	Review analysis	Comparison of existing studies
[24]	Energy efficiency obligations schemes	Numerical model	Calculation of real savings
[25]	South-East European power system in 2050	Cost-optimal analysis	Decarbonization scenarios
[26]	Heat savings scenarios	Least Cost Tool method	Cost-optimal mix of heat savings, district heating and individual heating
[27]	Smart energy grids	HOMER	Economic indexes
[28]	Zero emission city	ENERGYplan, TRNSYS	Energy and economic indexes
[29]	Energy transition	ENERGYplan	Transition strategies
[30,31]	Universities as models for sustainability	Numerical model	Case studies

Many papers focused on the problem of energy security [12]. Radovanic et al. [13] presented an analysis of the energy security measurement based on a geo-economic approach. The authors proposed a new approach to measure the energy security in a quantitative way. The new technique is based on a new geo-economic concept of energy security. The authors used the conventional indicators, combined with the sovereign credit rating in order to measure also the economic, financial and political stability. Using this technique, authors measured this newly proposed Geo-economic Index of Energy Security which showed significant deviations with respect to the conventional approach based on simple indicators. The authors concluded that the least impact on energy security is due to energy dependence and renewable energy production. Thus, the sovereign credit rating must be further investigated and the reliability of the energy dependence indicator must be verified in order to consider this index as a measure of energy security. März [14] focused on the fuel poverty vulnerability of urban neighborhoods using a spatial multi-criteria decision technique. They presented a case study for the German city of Oberhausen. Fuel poverty is becoming a critical issue in several EU countries. Therefore, several institutions are promoting specific policies in order to reduce households' fuel poverty vulnerability. However, such programs are not able to reach people really needing help since it is not easy to identify poor people needing such support. In this framework, the author developed a new approach based on GIS- Multi-Criteria Decision Analysis (MCDA), using an Analytical Hierarchy Process (AHP). The analysis was performed considering three vulnerability dimensions: heating burden, socio-economic and building vulnerability. Then, they proposed an overall Fuel Poverty Index in order to investigate the relative fuel poverty vulnerability of 168 urban neighbourhoods. The authors of this study concluded future policies must consider a trade off between ecological and social targets. This problem was also investigated by Okushima [15], who

proposed a new multidimensional energy poverty index (MEPI), to be used to evaluate energy poverty. MEPI includes three dimensions, to be used only for the case of developed countries: income, energy costs and efficiency of housing. This methodology is applied to the area involved in the Fukushima accident. Results show that since the 2000s, Japan has suffered a remarkable aggravation of its energy poverty. Vulnerable households are in a serious energy poverty situation. In addition, the increase of energy prices, caused by the Fukushima accident, dramatically affected the energy poverty of vulnerable households and the elderly. In all these studies, authors remarked that societal aspects must be carefully addressed in order to achieve the goal of a sustainable energy transition [16].

Several papers focused on a clean transition of the mobility sector [17]. Ajonovic and Hass [18] compared the different emission reduction policies (e.g., incentives for biofuels, threshold for specific CO<sub>2</sub> emissions, fuel and registration taxes, etc.) in Europe in the car mobility sector. Using the ALTER-MOTIVE model, they found that greenhouse gas (GHG) emissions can be reduced by 33% in 2030 compared to the Business as Usual (BAU) scenario. They also concluded that several different measures and alternative technologies and fuels must be simultaneously used in order to achieve a significant reduction of GHG emissions. A similar study was also performed by Knez et al. [19], regarding the development of electrical vehicles. Dominkovic et al. [20] investigated the role of the transportation sector for a sustainable clean energy transition. This sector accounts for about 30% of the total energy consumed in EU and a huge effort must be performed in order to reduce energy demand and emissions. Obviously, this circumstance is mainly caused by heavy-weight vehicles and by long-range vehicles. A dramatic energy consumption is also caused by airplanes. The authors performed a comprehensive literature review in order to detect possible solutions. The energy transition could be obtained by implementing four different actions: biofuels, hydrogen, synthetic fuels (electrofuels) and electricity. Results showed that the possibility of using electric vehicles has the largest impact on the overall energy and emission balance. The authors estimated that in EU 72.3% of the transport energy demand could be directly electrified by the technology existing today. For the remaining part, 3069 TWh of additional biomass was needed for biofuels. In addition, 2775 TWh of electricity and 925 TWh of heat were also needed for renewable electrofuels. Firak et al. [21] analyzed a future scenario where the Croatian transportation sector is dominated by fuel-cell vehicles and hydrogen infrastructure. In particular, authors calculated the volume of hydrogen required to supply the tourist's hydrogen fuel cell vehicles for three phases up to the year of 2030. The authors assumed that hydrogen will be produced via water electrolysis driven by PV fields located at suitable sites. Hydrogen refueling stations sites are proposed on the basis of traffic volumes on selected road directions in Croatia (mostly approaching the Adriatic coast). This approach will determine a dramatic reduction of GHGs emissions. In addition, the proposed system will allow one to solve the issues related to energy storage and clean transportation. The problem of the sustainable development of the transportation sector was also investigated by Briggs et al. [11], focusing on the simulation of non-automotive and off-highway vehicles. This work analyzes the simulation techniques for such vehicles comparing the approach based on drive cycle testing and experimental validations. The study considers two case studies: an urban hybrid diesel-electric bus and a forklift truck powered by an Internal Combustion Engine (ICE). A novel sustainable mobility system for campsites was investigated by Del Moretto et al. [22]. The authors evaluated a sustainable mobility connection among three campsites and the coastal area of Tuscany, Italy. They considered two alternatives, namely: a diesel tourist train and an electric tourist train. The two alternatives were compared considering energy, environmental and socio-economic aspects. They concluded both solutions can be viable when suitable funding policies are implemented.

Knoop analyzed the energy efficiency targets for the EU [23]. In 2014, the EU planned a minimum 27% energy efficiency improvement by 2030. These targets must be achieved by voluntary actions set by each Member State, which may also set more restrictive national objectives. However, there is still much debate regarding the potential improvements for each Member State. Therefore, this paper aims to fill this knowledge gap, providing a review of scientific works investigating the possible improvements in

energy by each EU Member States by 2030. The analyzed papers detect a significant potential for energy efficiency, showing very different outcomes, depending on the analyzed country. In the worst scenario, 10–28% energy savings could be achieved by 2030 with respect to the BAU scenario. Conversely, in the best case, 7–44% can be achieved. Energy efficiency potentials range between 14% and 52%, depending on the selected EU Member State. Moser [24] analyzed the energy efficiency obligation schemes. Such measures are used in order to implement energy saving actions. Such schemes were adopted as a consequence of the EU Energy Efficiency Directive and EU Institutions claim that determined a significant increase of the energy savings at relatively low costs. However, this paper criticizes these optimistic results since in author's opinion, the energy savings are dramatically overestimated. This idea is based on the fact that bargaining processes determine an improvement of the accredited savings of each considered measure. In addition, the author pointed out that non-standardized methods of measurement may determine a remarkable overestimation of real savings.

Pleißmann and Blechinger [25] focused on the decarbonization pathway for South-East Europe (SEE) in order to achieve 2050 EU mitigation goals. The authors implemented a multi-regional power system model to investigate an economically viable decarbonization pathway for SEE countries. The authors discuss the optimal strategies to be implemented in the power sector. On the other hand, they neglect cross-sectoral demand shifts due to the heat pumps and electrical vehicles. Results show that a huge effort must be performed to meet the decarbonization targets. SEE must implement important actions in order to achieve the GHG emission reduction targets: PV and wind capacities must be increased by 120.7 GW and 92.4 GW by 2050, respectively; transmission capacities to near countries must be increased by 32.7 GW until 2050. High investments are expected to achieve these goals. As a consequence, the levelized cost of power supply will be 12.1 ctEUR/kWh.

Many papers focused on the clean energy transition related to urban areas. Amer-Allam et al. [26] focused on the Danish municipality of Helsingør, trying to evaluate possible reductions in energy consumption and emissions. The authors analyzed the heating system of Helsingør developing future scenarios in order to detect the combination of individual heating, district heating and heat savings, maximizing system economic profitability. Results show that in 2030: (i) the heating demand can be reduced by 20–39% by implementing heat savings; (ii) 32–41% of the overall heat will be supplied by district heating systems; heating-related CO<sub>2</sub> emissions will be reduced by up to 95%. In 2050, in the optimal thermo-economic scenario, the share of district heating in Helsingør will increase by up to 44%. The topic of energy management in municipalities was also investigated by Batas-Bjelic et al. [27]. The authors used HOMER to simulate a smart grid proving heat and electricity to a municipal area. The final goal was the reduction of yearly energy costs. A number of different technologies were considered, namely: wind power plants, PV plants, combined heat and power (CHP) plants. Such a plurality of devices is crucial in order to manage fluctuating renewable energy production and the excess heat from cogeneration plants. The results of the simulations proved the economic and environmental benefits of the proposed smart municipal energy grids. From the economic point of view, the internal rate of return is ranged between 6.87% and 15.3%; CO<sub>2</sub> emissions varied from –4885 to 5166 t/year. The calculated number of CHP operating hours varied from 2410 to 7849 h/year. Another study aiming to analyze the possible transition to a clean energy system at urban level was presented by De Luca et al. [28]. The goal of this study is to convert an Italian city to a zero greenhouse gas city by 2030. They proposed to use a number of efficient technologies, namely: wind turbines, photovoltaic panels, biogas cogeneration, thermal solar panels, cogeneration and heat pumps. They combined both ENERGYPlan and TRNSYS software to perform their analysis. The results show that calculated thermal and electric energy prices are very promising: 0.11 €/kWh<sub>e</sub> and 0.12 €/kWh<sub>t</sub>, respectively. Therefore, the whole system is also economically profitable. ENERGYPlan was also used by Vidal-Amaro et al. [29] to design an electrical renewable energy system in Mexico. In this paper several scenarios for the development of renewables for the Mexican electricity system were analyzed, aiming to meet the target of a 100% renewable system. Presently, the Mexican electricity system generates 260.4 TWh/year (85% based on fossil fuels) of electricity. The authors



evaluated the impact of a higher utilization of several renewable technologies (PV, wind, geothermal, biomass, hydro and concentrating solar power) on the system capacity to match user demand. Several other studies are available in this area regarding universities [30,31]. In all the cases, universities are taken as models for the development of sustainability and energy efficiency actions and the implementation of the climate strategies.

Similarly, this topic was analyzed in detail in previous SDEWES special issues paying attention to a number of different aspects, namely: the role of energy prices as a driving force towards a sustainable development [32], renewable energy integration in an EU northern power market [33], impact of electric vehicles on the Croatian transportation system [34], carbon emission reduction targets for New Zealand in 2050 [35], guidelines for power utilities to reach specific decarbonization targets [36], the role of PV and concentrating solar power for the decarbonization targets [37], policies and subsidies to support renewables [38,39] and many others [40–48].

## 2.2. Polygeneration and District Heating

The topic of polygeneration, with special focus on district heating and cooling systems, was widely discussed during the previous SDEWES conferences. As a consequence, dozens of papers dealing with this topic are included in previous journal special issues dedicated to the SDEWES conferences. The following Table 2 presents the main features of the main papers analyzed in this subsection.

**Table 2.** Main topics, methodologies and outcomes of the previous SDEWES papers dealing with polygeneration and district heating.

Reference	Topic	Methodology	Main Outcomes
[49]	District heating systems	Measured data	Comparison between two systems
[50]	District heating systems	Modelica <sup>®</sup> library	Simulation tool
[51]	Power and water distribution networks	Multi-objective model	Design procedure for power and water distribution networks
[52]	District heating systems	Numerical model	A model for planning and scheduling of district heating systems
[53]	Renewable district heating	TRNSYS	Energy and economic indexes
[54]	Biomass trigeneration system	Optimization model	Energy and economic indexes
[55]	Cogeneration	Review and market analysis	Evaluation of the profitability
[56–63]	Polygeneration	TRNSYS	Energy and economic indexes
[64]	Polygeneration including desalination	Exergy and exergoeconomic analysis	Exergy, energy and economic indexes
[65]	Polygeneration including desalination	Energy analysis	Energy indexes
[66]	Trigeneration	Energy and economic analysis	Feasibility for small islands
[67]	Polygeneration	Review Analysis	Feasibility indexes
[68]	Biomass Cogeneration	Numerical Model	Feasibility analysis
[69,70]	Cogeneration and wastewater treatment	Aspen	Energy and economic indexes
[71]	Cogeneration	Energy and economic model	Simulation tool

Several papers specifically focused on district heating and cooling networks, paying special attention to the novelties in terms of research and development [72,73]. A comparison between district heating systems in Zagreb and Aalborg was presented by Culig-Tolic et al. [49]. They aimed to analyze similarities and differences in order to improve the systems. The authors concluded that the Aalborg district heating system is better than the Zagreb one. This district heating system can be improved by replacing pipes in order to decrease water and heat losses. In addition, lowering hot stream temperature is crucial in order to promote the integration with renewable energy sources. Arce et al. [50] presented the results of the project funded in the framework of the FP7 programme. They developed a modeling platform of heat transport in district heating systems. The platform includes several models of the components of the district heating systems. A code-to-code validation

procedure is presented in order to test the accuracy of the proposed simulation platform. The developed model showed a good agreement in steady state. On the other hand, some significant deviations are detected in the case of highly dynamic phenomena. Gonzales-Bravo et al. [51] also focused on district networks (energy and water) presenting a novel approach considering simultaneously economic, environmental and social aspects. In particular, the novel method presented in this paper also considers the variety of criteria for the stakeholders involved in the design of operational strategies and new facilities. A multi-objective model was used in order to consider this plurality of different objective functions. This method selects system layout and design parameters as a tradeoff between the multiple stakeholders. A case study was presented by Hermosillo, Guaymas and Obregon for the problem of the water scarcity in Mexico. The results of this analysis show that this approach may determine significant economic, environmental and social benefits for inhabitants and a good profitability for the investors. The optimal size of district heating and cooling systems was also investigated by Pavicevic et al. [52]. The authors argued that the optimization of district heating and cooling systems is typically a very hard task, due to the large number independent variables and the large time horizons (at least one year), requiring a huge computational effort. This paper aims to develop an optimization model capable to calculate both design and operational parameters. The proposed district heating system includes the following components: solar thermal collectors, boilers, electric heaters, heat pumps and thermal storage units. The authors simultaneously consider building refurbishment. Nine different scenarios were considered in the analyses. The results show that the proposed renewable system is economically profitable with respect to a conventional systems based on boilers. A novel district heating and cooling system was investigated by Carotenuto et al. [53]. The system was fed by a plurality of renewable sources (geothermal, biomass and solar) and it was operated at low temperature. In particular, geothermal wells, evacuated solar thermal collectors and auxiliary wood-chip boilers are used in winter. In summer, cooling energy is provided by an adsorption chiller. The system produces domestic hot water all year long. A suitable dynamic simulation model, developed in TRNSYS, is used to perform the calculations. A case study is presented for the town of Monterusciello, near the city of Pozzuoli, in the South of Italy where a geothermal source is available at about 55 °C. Buildings rehabilitation is also considered. The results show that during winter geothermal and solar energy are only used for thermal purpose. In summer the auxiliary biomass boiler must be mandatory activated to meet the space cooling demand. The energy performance of the system is satisfactory since solar collector efficiency is above 40% and the Coefficient of Performance of the adsorption chiller is about 0.5. However, the system is far from an economic feasibility.

The idea of polygeneration consists in the simultaneous production of different energy vectors (electricity, cool and heat) and byproducts using both fossil fuels and renewables. A plurality of renewable energy sources may be used in polygeneration systems [54]. This topic is extremely attractive since this technology is expected to dramatically reduce energy consumption and emissions. Cogeneration is the simplest case of polygeneration systems [55]. As a consequence, many papers were published in this area in the previous SDEWES Special Issues. Calise et al. [56] presented a novel layout of a polygeneration system for the island of Pantelleria. The system supplies energy to a district heating and cooling network and it simultaneously produce: electricity, thermal energy, cooling energy and desalinated water. The system layout includes: geothermal wells, Parabolic Through Collectors (PTC), a Multi-Effect Desalination (MED) and an Organic Rankine Cycle (ORC). A detailed dynamic simulation model was developed and special control strategies were proposed to manage the system. A thermo-economic analysis was also implemented and the results showed that the payback period was 8.5 years. Several other works dealing with polygeneration were presented by the same research group, analyzing solar assisted heat pumps system coupled with photovoltaic/thermal collectors [57], optimal control strategies for trigeneration systems [58], novel layouts integrating geothermal and solar energy, ORC and MED technologies [59], energy and exergy analyses of a novel system producing electricity, heat and cool and desalinated water based on Concentrating PVT and MED technologies [60,61], small-scale polygeneration systems based

on building integrated PVT collectors [62,63]. The integration of desalination technologies with cogeneration systems was also investigated by Catrini et al. [64]. The authors analyzed a Combined Heat and Power steam cycle coupled with Multi Effect Distillation-Thermal Vapour Compression, from both economic and exergy points of view. Here, a detailed exergy and economic model is presented. Different scenarios are evaluated. In a first scenario, concentrated brine is assumed to be discharged to sea, wasting its physical and chemical exergy. In a second scenario, a certain amount of the outlet brine is supplied to a Reverse Electrodialysis unit, producing electricity. Unfortunately, unit costs resulted high for both cases. The highest exergy destruction is due to freshwater in the first configuration and Reverse Electrodialysis electric output in the second one. A similar analysis was also presented by Tamburini et al. [65], focusing on retrofitting existing CHP systems using multiple effect distillation (MED) along with thermal vapour compression (TVC) technology. Polygeneration was also investigated by Beccali et al. [66] investigating the feasibility of the installation of trigeneration systems for a number of Italian islands. In particular, they focused on retrofitting existing power plants, evaluating the feasibility of heat recovery from the existing diesel engines and the related installation of a suitable district heating network. Six different islands were analyzed. For the analyzed case studies, different boundary conditions are considered, since several parameters (number of inhabitants, climatic conditions and touristic fluxes, etc.) are significantly different. The calculations are performed by detailed dynamic simulations and a number of scenarios were analyzed. The economic analysis showed that the proposed system is beneficial from an energy point of view but it is extremely far from an economic profitability, even when suitable funding policies are considered. Better results could be achieved only in case of a high number of permanent inhabitants. The results of the Energy Agency Annex 54 project (“Integration of Micro-Generation and Related Energy Technologies in Buildings”) was presented Angrisani et al. [67]. They presented a review of the available methodologies and indexes for the calculation of polygeneration systems performance. A novel index is also introduced and discussed in order to evaluate the system economic profitability. The reviewed indexes were calculated with respect to two alternative systems, using three commercially available cogenerators. The authors evaluated the feasibility of combined production with respect to the separated one as a function of the energy prices and users. In all the cases, thermoeconomic indexes showed good reliability and robustness. Cogeneration systems can be also supplied by biomass, as investigated by Pfeifer et al. [68]. They focused on biomass from unused agricultural land in Croatia. This type of biomass could be used to supply cogeneration systems up to 15 MWe. Their calculations showed that the novel systems including the combined heating and cooling plants with seasonal storage are not profitable. However, more conventional CHP systems would be feasible. Di Fraia et al. [69,70] analyzed the integration of CHP system in wastewater treatment plant. They proposed a CHP system fueled by the biogas produced by the treatment plant. CHP waste heat is used to dry outlet sludge. This arrangement allows one to dramatically reduce the costs for sludge disposal. The authors implemented a suitable energy and economic model and they calculated a payback period slightly lower than seven years. Piacentino et al. [71] presented a simulation tool for cogeneration systems, which optimizes the plant layout, the design parameters and their operation strategy. A case study is presented for a building in the hotel sector. The authors identified the most promising configurations as a function of: tax exemption and operating map of the engine.

Several other papers were published in this area in the previous SDEWES special issues, dealing with: trigeneration systems including fuel cells and supplied by municipal waste [74], building integrated trigeneration systems [75], cogeneration for wood industry in Serbia [76], simulation of a cogenerative micro-gas turbine operating at partial load conditions [77], cogeneration systems supplied by waste forest biomass [78], interaction between cogeneration systems and electrical vehicles [77,79], integration of solar energy in district heating systems [80], incentivizing mechanisms for trigeneration plants in Italy [81].



### 2.3. Advanced Combustion Techniques and Fuels

In order to improve heat conversion of various types of fuels several novel techniques were investigated during the previous SDEWES conferences. The main features of the papers analyzed in this subsection are summarized in the following Table 3.

**Table 3.** Main topics, methodologies and outcomes of the previous SDEWES papers dealing with advanced combustion techniques and fuels.

Reference	Topic	Methodology	Main Outcomes
[82]	Particulate filter for diesel boilers	Experimental analysis	New prototype based on Biomorphic Silicon Carbide (bioSiC)
[83]	Purification process of dry syngas	lab-scale test facility	High bed conversion of the impurity removal reaction
[84]	Catalytic decarboxylation of rubber seed oil for diesel fuel production	Aspen HYSYS V8.0	Energy and economic indexes
[85]	Bio-oil pyrolysis	Experiments in a fixed bed tubular reactor	Biochar yields decrease in case of lower pyrolysis temperatures and heating rates
[86]	Model of pollutant emissions in diesel engines	Numerical model in FIRE	Biodiesel blends release lower nitrogen oxide emissions
[87]	Thermoelectric generator fed by natural gas.	ANSYS/FLUENT	Optimal set of design parameters
[88]	Slab heating characteristics in a reheating furnace.	ANSYS/FLUENT	Optimal set of design parameters
[89]	Aqueous bioethanol combustion	Experimental test rig	The emissions of all the tested alcohols are compliant with the present Hungarian standard
[90]	Grate biomass furnaces with water boilers and condensing economizers	Experimental	New method for moisture evaluation
[91]	Energy storage system based on sewage sludge gasification	Numerical	Syngas suitable to be injected into a natural gas distribution network
[92]	Spark ignition engines fed by biogas	Experimental and numerical	Validates simulation tool
[93]	Pure tire pyrolysis oil	Experimental	Experimental data

Orihuela et al. [82] analyzed the possibility to use Biomorphic Silicon Carbide (bioSiC) as a particulate filter for diesel boilers. This material is a novel ceramic material which exhibits excellent thermal and mechanical properties and it is very attractive as article filter media of exhaust gases of diesel boilers. In this paper, authors designed and constructed an experimental setup to extract a sample of the boiler exhaust gas in order to filter it under controlled conditions. Several types of filters were experimentally analyzed, measuring the number and size of particles upstream and downstream. The results of the tests show that, for filters made from natural precursors, the efficiency dramatically depends on the cutting direction and associated microstructure. For samples derived from radially cut wood, a 95% initial efficiency of the filter is achieved. For samples obtained by an axial cut of the wood, the initial efficiency ranges between 70% and 90%. Then, due to the particles accumulation, the efficiency increases around 95%. Kobayashi et al. [83] analyzed the purification process of dry syngas. This syngas is produced by coal gas using oxy-fuel gasification and it is used in a combined cycle equipped with carbon dioxide capturing. This technology is extremely promising since it is expected to achieve thermal efficiency around 44%, simultaneously providing compressed CO<sub>2</sub> (93 vol %). The authors designed the dry syngas cleaning process and a lab-scale test facility to prove the feasibility pf the process. In particular, two types of sorbents were tested. The results, for both cases, showed enough removal within the satisfactory short depth of sorbent bed and a higher bed conversion of the impurity removal reaction. Cheah et al. [84] analyzed the catalytic decarboxylation of rubber seed oil for diesel fuel production in Malaysia. The process was simulated using Aspen HYSYS V8.0 and a suitable thermoeconomic model was also developed. The

authors calculated the minimum fuel selling prices in order to achieve a reasonable profitability. The simulated systems can process 65 kL/day of inedible oil producing 20 ML/year of renewable diesel. For this system, authors calculated a return of investment equal to 12.1%. Pehilivan et al. [85] analyzed the pyrolysis for bio-oil, char and gases production. They used cherry pulp which was tested in a fixed bed tubular reactor at different temperatures and heating rates. Several analyses were performed in order to analyze chemical alterations after the pyrolysis process. Experimental results showed that biochar yields decrease in case of lower pyrolysis temperatures and heating rates. Petranovic et al. [86] modelled pollutant emissions in diesel engines, analyzing the case of biofuels. They started from a literature review showing that there is no consensus regarding the influence of biodiesel in emission concentration. Therefore, they developed a suitable numerical model in FIRE environment in order to calculate such emissions. The model takes into account spray particles, combustion, fuel evaporation and disintegration and the chemical process for pollutant formation. The developed model was also validated using experimental data. Then, they compared the emissions of biodiesel vs the ones of conventional diesel engines. They found that biodiesel blends release lower nitrogen oxide emissions than the engines powered with the regular diesel. Another simulation model was presented by Bargiel et al. [87]. The authors developed a numerical model of a thermoelectric generator fed by natural gas. The rated capacity is around 50–100 W and the device is designed in order to supply electricity to remote objects of the natural gas infrastructure, where the electrical grid is not available. The numerical model was implemented in the ANSYS/FLUENT platform. An optimization procedure was implemented in order to optimize temperature difference across the thermoelectric module. An optimum response surface was calculated leading to a selection of the design parameters which will be subsequently used as a basis for the experimental analysis of the prototype. Wang et al. [88] analyzed slab heating characteristics in a reheating furnace. For this process, the performance is strictly related to the combustion process and to the fluid dynamics. The heating efficiency depends on a number of different parameters, such as: locations of both slabs and burners, type of fuel, geometry of slab supporting systems and thermal properties of slabs. A suitable finite-volume simulation model was implemented in ANSYS/FLUENT in order to perform the calculations. The results of the simulations showed that the best configuration was obtained in case of six side burners. Kun-Balog et al. [89] analyzed the process of aqueous bioethanol combustion in order to calculate the related pollutant emissions. A 12% ethanol-water solution was used to analyze the distillation process. Then, a suitable experimental test rig was used for the calculation of the combustion performance. During the tests, a 15 kW combustion power was used at an air-to-fuel ratio of 1.17. In addition, 96–50% ethanol-water solutions were used in the tests (both liquid and gaseous). The emissions of all the tested alcohols are compliant with the present Hungarian standard. Striugas et al. [90] focused on grate biomass furnaces equipped with water boilers and condensing economisers. These systems are widely used in Lithuania in district heating systems. Unfortunately, such systems are very sensitive to the inlet biomass composition which may determine an unstable system operation. Therefore, authors developed an indirect method to evaluate the moisture included in the fuel stream and this method was implemented in a suitable controller. The method was validated using the data of a 6 MW grate-fired furnace fueled by biomass, showing deviations below 3%. Kokalj et al. [91] developed a novel energy storage system based on sewage sludge gasification. A suitable thermodynamic model of the gasification process was used to analyze the performance of the system. The model returns the calculated syngas amount and composition. The aim of the study is to produce syngas suitable to be injected into a natural gas distribution network. To this scope, the best configuration is achieved gasifying sewage sludge with 35–40 wt % moisture. Conversely, the best performance is obtained with SS dried to 20 wt % of moisture content, when syngas is used onsite. Nunes de Faria et al. [92] developed experimental analyses in order to predict the performance of suitably modified spark ignition engines using biogas produced in a sewage plant in Brazil. The tests showed that the reduction in engine efficiency was higher than the advantages in terms of emission reduction. The authors also developed a zero-dimensional thermodynamic simulation model of the

system, based on a system of differential equations. The model allows one to calculate the pressure inside the cylinder, indicated power and the mean effective pressure as a function of the crank angle in several different engine operating conditions. The results of the simulations were consistent with the experimental ones, showing deviations below 5%. Vihar et al. [93] investigated the possibility to use pyrolysis oil produced from waste tires in an automotive Diesel engine. The authors aim to further extend the operating range towards lower loads by implementing a novel arrangement based on the exhaust gas recirculation and tailored main injection strategy. This study also provides a detailed experimental analysis of the particulate emissions of the tire pyrolysis oil. The authors found excellent results both in terms of performance and emissions. Gas recirculation in diesel engines was also investigated in several other papers [94,95].

Other papers were published in the previous SDEWES special issues in this area, investigating similar topics, namely: analysis of the fuel injection timing and ignition position in a direct-injection natural gas engine [96], effects of engine cooling water temperature on performance and emission biofuel engines [97], biofuel pellet torrefaction [98], bio-oil production [99] and thermal treatment [100], advanced fuels for gas turbines [101], coal and biomass cofiring [102], optimization of the furnaces of the aluminum industry [103].

#### 2.4. Biomass

Biomass is often considered crucial to achieve the goals in terms of sustainable development [104]. This is clearly reflected by a literature review of the previous SDEWES special issues which include a large number of papers investigating this topic, summarized in the following Table 4.

**Table 4.** Main topics, methodologies and outcomes of the previous SDEWES papers dealing with biomass.

Reference	Topic	Methodology	Main Outcomes
[105]	Substrate feed control in anaerobic digesters	Review analysis	Closed-loop feed control are often missing
[106]	Energy crops for biogas production	Life Cycle Assessment	System performance indexes
[107]	Biomass gasification	Dynamic neural network model	Simulation tool
[108]	Biomass from <i>Miscanthus giganteus</i>	Field experiments performed on a cultivation	Experimental correlations
[109]	Bioethanol production	Experimental	Experimental data
[110]	Phytoextraction by pyrolysis	Thermo-economic model	Economic indexes
[111]	Transesterification of rapeseed oil by butanol	Experimental	Experimental data
[112]	Bioethanol production from <i>Chenopodium formosanum</i>	Experimental	Experimental data
[113]	Bioethanol microalgae	Experimental	Experimental data
[114]	Biorefinery for lignocellulosic biomass	Numerical	Novel system layout
[115]	Sustainability of algal-based biorefineries	Review Analysis	Energy, economic and environmental indexes

In this field, biogas and gasified biomass are probably the most promising bio-fuels for their potential to decarbonize energy systems [116–119]. Gaida et al. [105] presented a detailed review of different strategies to control substrate feed in anaerobic digesters. Their analysis shows that the majority of full-scale biogas plants are not equipped with a closed-loop feed control. The control strategy is a tradeoff between economic profitability, ecological footprint and reliability. Such controls are sometimes used for anaerobic wastewater treatment, but it is not in use in agricultural or industrial biogas plants due to the lack of robust and reliable process monitoring. Lijo et al. [106] studied the effect of substituting energy crops for food waste as feedstock for biogas production. The authors

aimed to evaluate the environmental consequences of feedstock selection in biogas production. To this scope two different plants were analyzed using Life Cycle Assessment approach. Plant A performs the co-digestion of energy crops (78%) and animal waste (22%) while Plant B consumes energy crops (4%), food waste (29%) and animal manure (67%). According to the authors' calculations, producing electricity from biomass is better than the existing electric mix from the environmental point of view. Maize silage ( $650 \text{ Nm}^3/\text{TVSfed}$ ) and food waste ( $660 \text{ Nm}^3/\text{TVSfed}$ ) were identified as the most promising sources of bioenergy. The authors also concluded that specific guideless should be established in order to promote bioenergy environmental sustainability. Mikulandrić et al. [107] presented a numerical model of a biomass gasification process in a co-current fixed bed gasifier. In particular, they implemented a dynamic neural network model for biomass gasification in various operating conditions. The model is based on the data extracted from a co-current, fixed bed gasifier operated by TU Dresden. Results showed that the accuracy of the dynamic neural network model was higher than the one achieved by multiple linear regression models. In fact, it can predict process temperature and syngas quality with average errors lower than 10% and 30%, respectively.

Another interesting option is the cultivation of specific plants for energy purposes [120]. Szulczewski et al. [108] presented a new technique for the calculation of biomass yield of *Miscanthus giganteus* in the course of vegetation. The authors implemented a simplified approach where the biomass increase was simply modelled considering simple biometric measurements. The analysis is based on field experiments performed on a cultivation. On the basis of these data, an experimental correlation was determined between shoot volume index and shoot mass. The accuracy of estimation of is strictly dependent on the number of shoots. The authors concluded that the best tradeoff is obtained for 10 shoots of miscanthus. The results of the statistical estimation are satisfactory, showing relative errors below 17%. Ko et al. [109] analyzed bioethanol production from recovered Napier grass with heavy metals. These plants are used to absorb heavy metals from polluted soils. However, the management of the recovered explants may be extremely complex. Therefore, authors of this study proposed to convert it into bio-ethanol which is a very promising bio-fuel. The plants were used for soils contaminated by Zn, Cd and Cr. Unfortunately, such heavy metals also inhibit biomass production which is significantly lower (from 4% to 21% with respect to the case of uncontaminated soil, depending on heavy metal concentration). In addition, bacteria fermentation was enhanced by the presence of heavy metals. On the other hand, the fermentation efficiency was lower. The authors concluded that the overall effect of the utilization of Napier grass phytoremediation for bioethanol production is significantly positive for the sustainability of environmental resources. A similar study was also performed by Kuppens et al. [110] focusing on fast pyrolysis as a phytoextraction methodology. A suitable techno-economic analysis was performed to this scope. Kejek et al. [111] focused on the process of transesterification of rapeseed oil by butanol and separation of butyl ester. They present in detail the chemical processes occurring in this system, analyzing in detail the effects of the variations of the main independent variables: the amount of catalyst, the reaction temperature and time, the method of oil addition to butanol and the molar ratio of butanol. On the basis of the measured performance data, specific statistical correlations were developed. They concluded that using a strong acid significantly improves the separation process and it determines a zero content of potassium and free glycerol. The separation is enhanced also by the addition of a small amount of water and by the removal of butanol. In this field another interesting study was also presented by Yang et al. [112] presenting bioethanol production from *Chenopodium formosanum*. Cheng et al. [113] investigated the production of bioethanol using lipid-extracted biomass from a specific microalgae. They presented a new process where the lipid-extracted biomass was directly subjected to simultaneous saccharification and fermentation. The proposed system does not need any expensive pretreatment, also decreasing the contamination risk and complication of high sugar content. The results of their analysis showed the optimum configuration was found for temperature at  $36 \text{ }^\circ\text{C}$ , pH 5, 60 units/mL enzyme concentration, and yeast loading of 3 g/L. In such configuration, an overall conversion of more

than 90% of the theoretical yield was achieved with maximum bioethanol yield of 0.26 g bioethanol/g lipid-extracted biomass.

Biorefineries are also often studied as a viable option for a sustainable energy production. Özdenkçi et al. [114] presented a novel concept of integrated biorefinery for lignocellulosic biomass. The novel conversion technology is based on partial wet oxidation coupled with lignin recovery with acidification. The process is performed in reactor including hydrothermal liquefaction and supercritical water gasification. Thomassen et al. [115] presented a review of the sustainability of algal-based biorefineries. Their study aims to evaluate the data available in literature regarding both economic and environmental performances of such plants. In fact, they noted that algal-based bioenergy products have faced multiple economic and environmental problem. However, there is no consensus in literature about the sources of such problems. The performed literature review identified four main challenges: (1) the use of harmonized assumptions; (2) the adaptation of the methodology to all stages of technological maturity; (3) the use of a clear framework; (4) the integration of the technological process. The authors also proposed a specific methodology integrating techno-economic analyses and life cycle assessments. This technique can be iteratively performed for each stage of technology development. This methodology allows one to identify the crucial technological parameters and it can be useful in order to promote a commercial development of the proposed systems.

Other papers were published in the previous SDEWES special issues in this area, investigating similar topics, namely: biodiesel production from cooking oil [121], multiple biomass corridor [122], biomass for power solutions [123], hybrid solar biomass systems [124], biofuels for marine vehicles [125], production of biosolid fuels from municipal sewage sludge [126], analysis of active solid catalysts for esterification of tall oil fatty acids with methanol [127], analysis of woody biomass in Japan [128], biodiesel production using injection of superheated methanol technology [129].

### 2.5. Building Efficiency

Buildings account for about 40% of the overall energy consumption for the majority of developed countries [130–139]. Therefore, the reduction of building energy consumption is crucial in order to achieve the goals in terms of decarbonization recently established in Paris Agreement. To this scope, several actions are required, such as: building envelope refurbishments [140–142], optimization of the HVAC systems [143–149], utilization of renewable energy sources [150–156]. This topic was initially marginally investigated during the first SDEWES conferences. Then, due to the growing interest in this area, more and more papers were included in SDEWES special issues dealing with building energy efficiency. Several papers focused on passive buildings, as summarized in the Table 5 below reporting the features of the main papers involved in this topic.

**Table 5.** Main topics, methodologies and outcomes of the previous SDEWES papers dealing with building efficiency.

Reference	Topic	Methodology	Main Outcomes
[157]	Passive buildings	Simulation model in EnergyPlus	Optimal envelope features
[158]	Energy required for the manufacturing processes materials for buildings	Life Cycle Assessment	Overall impact of materials
[159]	Summer overheating in industrial buildings	Simulation model	Proposal of passive measures
[160]	Indoor confort in bioclimatic architecture	Review analysis	Methodologies for evaluating thermal confort
[161]	Insulating materials for buildings	Review analysis	Methodologies for evaluating thermal properties
[162]	Building energy performance	Numerical model	New methodology for the calculation of building energy performance



Chen et al. [157] presented a simulation model developed in order to optimize passive buildings. They started from a complete literature review of the papers available in literature, investigating simulation-based techniques for the optimization of passive buildings. Then, they proposed a simulation method developed in EnergyPlus environment. In particular, suitable control algorithms are applied to a local green building assessment scheme to control ventilation and lighting dimming. In addition, a NSGA-II genetic algorithm was used in order to calculate the Pareto Frontier and the final optimum as a function of: building layout and geometry, envelope thermophysical properties and infiltration and air-tightness. This approach allows one to design optimal passive buildings in different operating conditions. Passive buildings were also investigated by Kovacic et al. [158] focusing on the energy required for the manufacturing processes of several materials used for the construction of such buildings. The problem was analyzed also considering environmental aspects. A case study for a passive housing block in Austria was investigated. The authors implemented the Life Cycle Assessment (LCA) technique, using the real data available by an energy monitoring campaign. LCA returns the environmental impacts of the building materials, HVAC systems, and the operational energy for time scenarios of 20, 50 and 80 years. Results show that distribution pipes accounts for 10% of the Global Warming Potential. In addition, authors concluded that the passive house performs only slightly better in terms of environmental impacts, with respect to a reference case. The same research group also presented an overview of the strategies for the renovation of building stock for ageing society [163] and a life cycle optimization tools for building early design phases [164]. Gourlis et al. [159] analyzed passive measures for preventing summer overheating in industrial buildings. In industrial buildings space cooling demand is dominated by the internal gains due to the production process which may be very fluctuating. The authors analyze different retrofit scenarios for a case study in Austria. Specific measurements were performed in order to analyze the indoor climate conditions for the reference scenario. Then, using a suitable simulation model, energy efficiency actions were analyzed. The authors found that several actions are available for reducing overheating risk. In another paper, authors implemented Building Information Modelling (BIM), for the analysis of energy efficiency actions in industrial buildings [165].

Beccali et al. [160] presented a literature review of the implications of indoor thermal comfort and bioclimatic architecture in hot-humid climates. The paper analyzed in detail the methodologies commonly used in literature to evaluate thermohygrometric comfort in buildings featured by natural ventilation, based on adaptive approaches. The authors focus on the Mozambican buildings, analyzing a new healthcare facility. The same research group also implemented a specific tool (based on an artificial neural network) for assessment of the energy performance and the refurbishment actions for the non-residential building stock in Southern Italy [166]. Ricciu et al. [161] presented a review of the methodologies for the calculation of insulating materials for buildings. The authors analyze the available techniques for the calculation of the heat capacities of materials, paying special attention to the thermal behavior of lightweight insulation materials. For all the cases, the relationship between these properties and energy efficiency and indoor comfort were discussed. The paper also includes a new simplified approach for the estimation of the specific heat capacity, showing errors around 5%. Horvat et al. [162] presented a novel methodology for the calculation of building energy performance. Their approach is based on a detailed mathematical model for the calculation of indoor temperatures, space cooling and heating and domestic hot water demands. A case study is presented for a family house. The results are compared with the ones of EN ISO 13790 and EN 15316, showing significant differences in determination of the energy demands.

Further papers dealing with this topic can be found in the previous SDEWES special issues, investigating other aspects, such as: retrofitting actions for historical buildings in Italy [167], building water and energy regulations in England [168] and in Indian Hill Towns [169], energy monitoring of an apartment [170], definitions of suitable typologies representing residential building stocks [171], natural ventilation strategies for near zero energies school buildings [172], Energy Performance

Certification for faculty buildings in Zaragoza (Spain) [173], building energy demand for hotels, hospitals, and offices in Korea [174].

### 3. Research Topics Represented in This Special Issue

This special issue includes 17 papers from the 12th SDEWES Conference selected for this SI. This section briefly summarizes the methodologies and the main findings of those papers.

#### 3.1. Energy Policy and Energy Efficiency in Smart Energy Systems

Van de Dobbelsteen et al. [175] presented the results of the EU City-zen project which aims to develop an urban energy transition methodology to be used by the cities in order to achieve the goals of sustainability and carbon neutrality. In order to disseminate the results of the project and to implement the proposed methodology a number of Roadshows are organized in cities aiming to achieve sustainable lifestyle e carbon neutrality. In those Roadshows, experts from across Europe cooperate in order to propose strategies and timelines with the local stakeholders to achieve the above mentioned goals. One of these Roadshows was related to the district of Gruz, in the city of Dubrovnik. A detailed analysis of the peculiarities of this district was performed in order to detect possible actions to be implemented to improve sustainability and carbon neutrality. The analysis showed that the majority of the problems were related to the cruise ships and to the related tourists' activity. An energy master planning was implemented in order to define the actions to be implemented. A number of strategies are implemented, such as energy renovation of the buildings of the district and a complete renovation of the port based on renewables and algae arrays for cruise ships waste water treatment. These actions were negotiated with the local population and stakeholders and they may significantly improve the environmental impact.

The promotion of efficiency was also investigated by Sousa et al. [176]. The authors focused on the Portuguese Electricity Demand-Side Efficiency Promotion Plan (PPEC), which is a voluntary financial tool used to submit energy efficiency proposals. This plan is directly related to the EU Energy Efficiency Directive (EED), introducing Energy Efficiency Obligations (EEO). According to EEO, each energy company must achieve an energy saving of 1.5% of the overall energy consumed by the customers. This paper aims to analyze the role of the PPEC mechanism Portugal in relation to EU commitments. The authors performed a review of the existing Market-Based Instruments for energy efficiency in the world, detecting 46 mandatory and six non-mandatory schemes. The majority of those schemes were related to USA and EU. In the case of Portugal, where no EEO were adopted, such efficiency actions may be adopted both by the Distribution System Operator (DSO) and by private companies under the PPEC mechanism. The results of the overview showed that during the previous six PPEC editions, the number of promoters increased more than 10 times. In the same period, 3.6 times additional measures were implemented. Such measures are mainly related to public lighting or traffic lighting, lighting in buildings. In the same period, the total investment determined by PPEC increased nearly four times. Thus, authors concluded that PPEC is an effective mechanism to promote energy saving and energy efficiency.

Another possibility to increase efficiency and sustainability for cities is the so called "Hydrogen Economy", investigated by Kilkis et al. [177]. In this work, authors start from the idea of smart energy system where hydrogen plays a key role in the interactions between renewables, fossil fuel power plant and user demand. In fact, surplus electricity can be converted in hydrogen by electrolysis and this hydrogen can be subsequently used for power production in fuel cells during peak demand hours. In particular, authors assume to produce hydrogen using renewables and to use the existing natural gas pipelines to distribute hydrogen which is supposed to be used by fuel cells. The authors design a novel "hydrogen city" with two cycles at building and district levels. In the first cycle, the electricity of wind turbines and third-generation PVT panels is used to produce hydrogen by electrolysis. In the second cycle, fuel cells are supplied by hydrogen and supply thermal, cooling and electrical energy and water to a low-exergy buildings. Cooling energy is produced by an absorption

chillers supplied by the waste heat of the fuel cell. Suitable thermal energy storage systems (TES) are also included in the system. The system was also integrated with ground source geothermal heat pump and geothermal ORC in a “Circular Geothermal Option”. The results for the hydrogen city model and Circular Geothermal option showed that the two hydrogen cycles at the district and building levels dramatically improve the possibilities to reach near-zero exergy targets. The proposed systems allow one to improve the utilization of renewables, also increasing the savings in terms of emissions with respect to the reference values, including avoidable CO<sub>2</sub> emissions. The authors also concluded that the integration energy-water nexus, renewables, hydrogen economy and net-zero targets is crucial in order to achieve a sustainable energy system.

### 3.2. Polygeneration and District Heating

Doracic et al. [178] focused on the utilization of the excess heat in district heating systems. The majority of EU countries consider cogeneration as a crucial technology in order to achieve the targets in terms of energy efficiency and CO<sub>2</sub> reduction. To this scope, district heating networks are often used in order to deliver heat to the final users. Unfortunately, we are far from a massive utilization of this technology, since in EU only 13% of the heat supply is covered by district heating networks. However, this share increases up to 50% for northern countries and it is expected to achieve 70% by the next few years. The novel district heating networks will also include renewables and low-temperature heating systems (e.g., heat pumps), thermal storages, utilization of industrial thermal wastes and a suitable integration with the electricity network. These novel district heating systems (4th generation) will be also managed by advanced ICT technologies, fully integrated in the smart cities framework. In such novel networks, which include a plurality of production devices, the optimal management of heat sources is a crucial point in order to achieve good economic profitability. In particular, authors focused on a specific case study related to the city of Ozalj, implementing a suitable simulation model using both Matlab and QGIS software. The input data were obtained by a survey performed for 391 households, classified in eight different categories. The authors combined the data of this survey and the data regarding building gross area and localization in order to calculate the heat demand map. Then, they calculated the levelized cost of heat for a possible scenario considering a natural gas district heating system. In such calculations, both operating and capital costs were accurately considered. In a second scenario, a part of the heat provided by the natural gas was replaced by the excess heat provided by facilities, located outside the city. On the basis of the calculated heat demand map, authors identified the parts of the city where the installation of the district heating network was feasible. For these areas, they calculated a final heat demand equal to 75 MWh/year, obtaining a levelized cost of heat much lower than the one achieved by other conventional technologies. Their analysis also showed that the second scenario was feasible considering possible range of variation of excess heat supply, costs of pipes and heat price. From the environmental point of view, CO<sub>2</sub> emissions reductions up to 87% can be achieved by implementing the district heating network.

Taneczuk et al. [179] analyzed the technical possibilities to use district heating boiler slag in order to recover further thermal energy. In the framework of a development of sustainable, efficient and environmental friendly energy paradigm, it is crucial to recover energy by whatever source. The authors considered that a significant potential of energy recovery may be obtained by the utilization of the physical enthalpy of the combustion solid products, such as slag, due to their high temperature (250–450 °C). This energy accounts for about 3.5–25% of the total input primary energy. Thus, it seems extremely interesting the possibility to use the hot slag produced by the boilers fired with solid fuels. The authors describe a new process for the heat recovery from district heating grate-fired boiler slag. The proposed system includes two cogenerative engines (steam turbine and gas turbine), one coal fired water boiler, two hard coal stoker-fired water boilers. In order to perform the research, authors measured both volume and temperature of the slag leaving the boiler. They noticed that slag temperature was strictly related to the boiler load, varying from about 300 °C to 900 °C as a function of boiler output capacity. The authors assumed to use the slag heat in order to supply a high

temperature heat pump transferring the heat from the water in the deslagger to the district heating network. The authors also proposed two modifications of the system in order to enhance its efficiency, namely: direct heat recovery in the existing slag trap extended by a heat exchanger; direct heat recovery in the existing slag trap. Results showed that the waste heat available is low (lower than 1% of boiler maximum thermal output). However, results also validated the technical feasibility of the two proposed modifications which are economically feasible only in certain circumstances.

Gimelli et al. [180] proposed a novel optimization algorithm for polygeneration systems. Polygeneration is a novel and efficient technology where multiple energy vectors (electricity, heat and cool) can be produced simultaneously along with different types of byproducts (hydrogen, desalinated water, glycerin, etc.) using both fossil fuels and renewable energy sources. Polygeneration systems are expected to dramatically contribute to the goals in terms of energy efficiency and reduction of emissions. However, such polygeneration systems are extremely complex systems which include a plurality of different devices. Therefore, such systems can be competitive from both energy and economic points of view only when a rigorous optimization is performed, in order to calculate the optimal set of design parameters. In this framework, authors propose a novel optimization algorithm which takes into account the main external conditions. In particular, authors implemented a vector optimization process which is able to determine system layout, fluid selection and design parameters using a Pareto dominance approach. The optimization is performed using a Genetic Algorithm. A case study is analyzed for a cogeneration system based on an Organic Rankine Cycle (ORC). The Pareto front was reported as a function of the Primary Energy Saving (PES) and Simple Pay Back period (SPB). Here, dominant solutions showed PES higher than 16.5% and SPB around 3–5 years.

### 3.3. Advanced Combustion Techniques and Fuels

Kazagic et al. [181] analyzed co-firing low-rank Bosnian coals using different types of biomass, focusing on ash-related problems and emissions. They presented the state of the art showing that conventional fossil-fuel based power stations are going to be converted into multi-fuel power plants. In such hybrid systems a plurality of different biomasses are co-fired with coal aiming at improving fuel mix diversity and at improving the security of energy supply system. In this framework, authors focused on an experimental analysis of co-firing Bosnian low-rank coal with different types of biomass. In particular, they focused on woody biomass and *Miscanthus*. In their system, a multi-fuel pulverized combustion concept was proposed. The tests were performed using a lab-scale furnace, aiming at determining the optimal values of: operating temperature, air distributions, fuel portions and reburning ratio. Six different fuel combinations were considered in the experiments whose composition was accurately measured before the tests. The lab-scale furnace includes an alumina-silicate ceramic tube combustor, surrounded by SiC electric heaters and a suitable insulation. The temperature of the reaction zone is controlled in the range from ambient to 1560 °C. The results of the experiments showed that the tested blends could be used in real systems. In all the cases major ash-related problems were not detected. For all the tested mixtures, a marginal or medium slagging propensity was detected. A minor increase of unburnt carbon content (UBC) in the ash deposits was detected when the co-firing rate was increased from 0.0 to 0.3. Conversely, in the slag collected at the bottom of the furnace, the UBC significantly increased for 0.15 and 0.2 biomass co-firing. From the emissions point of view, results showed that SO<sub>2</sub> emissions remained within the expected limits. NO<sub>x</sub> emissions slightly varied among the different considered fuel mixtures, showing a general decrease in case of higher biomass co-firing rates.

Eder et al. [182] presented a 3D CFD model of a Diesel ignited gas engine. The analysis was applied to large engines, typically used for marine application, where conventional diesel systems are going to be hybridized in dual-fuel (natural gas and Diesel) engines. In particular, authors focused on the Diesel ignited gas engines where a small amount of Diesel fuel is injected into the lean mixture. This technology allows one to enhance fuel flexibility and to decrease NO<sub>x</sub> and soot emissions. Conversely, a lower efficiency is achieved with respect to the case of gas fired engines. The simulation

of such dual-fuel engines is a very hard task since several combustion mechanisms are included in system physics. As a consequence accurate 3D CFD models, including detailed calculations of the rates of reactions, are required in order to calculate and the 3D transient flame front propagation. To this scope authors implemented detailed models in order to take into account the ignition process and delay in a dual fuel operation. In order to perform a model validation, a suitable experimental setup was used. In particular, a Bosh Tube was used in order to measure the rate of injection. Results of the experiments showed a reasonable agreement between numerical and experimental data. Similarly, the combustion model was also validated against experimental data (provided by SCE in Graz). In this case, the calculated heat release related to the flame front propagation was higher than the corresponding measured data.

#### 3.4. Biomass

The utilization of biomasses for energy purposes was also investigated by Guimaraes et al. [183], focusing on the development of an anaerobic digester supplied by food waste and sewage. In fact, in many countries the problem of the final disposal of municipal solid waste is extremely critical, causing environmental, social and economic issues. This is especially crucial for the organic matter which is dominant in the solid municipal waste of several countries like Brazil. However, a well-established technology (anaerobic digestion) allows one to stabilize such organic matter and to produce biogas which can be used for electricity and heat production. For a massive utilization of this technology a further research effort is required in order to reduce capital cost and implement optimized control and management strategies. This is the scope of this paper. The research is based on the samples of raw sewage collected by a wastewater treatment plant in Rio de Janeiro. Inoculum was collected from an Upflow Anaerobic Sludge Blanket at a local industry. Food waste was collected at meal time. The components were mixed and their parameters (COD, TS, PH) were properly measured. These samples were subsequently used in experiments in lab-scale bioreactors consisting in glass cylinders. Then a suitable control system was designed and installed on a PLC communicating with a supervisory software. During the experiments, different mixtures of the components were used in order to detect the optimal configuration. In this second part of the work, three biodigesters (B1, B2, and B3) were built. The three biodigesters contain different mixtures, namely: B1 food waste and Sewage; B2 Food Waste, Sewage and Anaerobic Sludge (inoculum); B3 Food Waste, Water and Anaerobic Sludge. Experiments were carried out for 60 days. B2 showed the best performance in terms of: biogas production (63 L), methane return (95%), TS, TVS and COD reductions. This result is due to the composition of substances present in sewage.

Tic et al. [184] proposed an innovative system for the sustainable utilization of sewage sludge. This waste mainly contains water and some organic matter, including microorganisms and various pollutants. Conventional management techniques are often inefficient and harmful for the environment and therefore EU promotes the utilization of novel techniques providing waste stabilization, energy recovery and recycling. In fact, due to the severe environmental restrictions, conventional utilization pathways (e.g., landfilling) are going to be replaced or combined with novel thermal processes. In this framework, authors focused on the drying and torrefaction of sewage sludge, combined with a gasifier and an engine for maximizing heat recovery. In particular, they started from a detailed analysis of the state of the art regarding dewatering and drying of sewage sludge, slagging gasifiers, inertization of solid residues and plasma gasification. Then in order to perform their analysis, a number of samples were obtained by the sewage treatment plant in Brzeg Dolny. These samples were used in two experimental setups. The first one, is a paddle dryer operated in batch mode which includes a number of meters required to measure all the relevant thermodynamic parameters. The second one is used to perform torrefaction tests which were carried out at a laboratory scale using isothermal rotary reactors. Here, gas analyzers, gas chromatographs and spectrometers were used in order to measure properties of inlet and outlet streams. Results of the tests showed that a partial drying dramatically increased electricity consumption. In fact, sludge is a non-Newtonian fluid and its



viscosity dramatically increases in case of a lower water content. Torrefaction of the dried sewage sludge determined a marginal carbonization of the sludge and a relevant reduction of the moisture. GC-MS analysis showed remarkable amounts of different heterorganic compounds in the torrefaction gas. All these results are in line with the data available in literature.

### 3.5. Building Efficiency

The goal of a sustainable and efficient development can be also achieved reducing building energy consumption. In fact, buildings account for about 40% of the total final energy use. In this framework, Berardi et al. [1] presented a study dealing with dynamic modeling of building energy demand. In buildings, energy demand is mainly due to space heating and cooling which, in turn, depend on the peculiarities of the building envelope and on internal and external loads. A detailed time-dependent calculation of such demands is crucial in order to analyze the energy and economic feasibility of refurbishment actions. In addition, such calculations also affect the selection of the HVAC systems maximum capacity which dramatically affects the overall energy and economic performance of the buildings. In fact, when the selected capacity is higher than the required value, a higher capital cost is achieved and the production devices will operate in part load conditions where the efficiency is lower. Therefore, this paper analyzes temperature dependence of thermal conductivity. The authors implemented a suitable thermodynamic and hygrothermal model based on energy and mass balances in order to perform their calculation. Suitable measurement were performed in order to calculate the temperature-dependent functions of thermal conductivity. Such equations are subsequently implemented into the building simulation model in order to evaluate the variations of conductivity during the year. Results were compared to the conventional ones considering constant thermal conductivities. Results showed that for Turin the conventional techniques underestimate building thermal demand. Conversely, in Rome and in Palermo the difference between the conventional and the proposed technique is negligible, since winter temperature variation is limited. In summer conditions, the results depend on the sign of the average heat flux.

Obviously, the above mentioned goals may be also achieved by the utilization of conventional and innovative renewable energy technologies. In particular, for novel renewable technologies it is crucial to evaluate its economic profitability with respect to conventional ones. An example is reported by the work by da Klimes et al. [185] which compares an innovative renewable system (solar chimney) with a conventional one (photovoltaic, PV). A solar chimney converts the solar thermal energy of radiation into the kinetic energy. This kinetic energy may be converted in electricity by a wind turbine or used only for ventilation purposes. In fact, the solar chimney is beneficial for the building due to the increased ventilation rate which reduces the space cooling load. Several works are available in literature investigating solar chimneys from both numerical and experimental points of view. However, the profitability of those systems must still be proven. Therefore, in this study, authors compare a solar chimney with a PV-based fan providing the same ventilation rate of the solar chimney. The calculations were performed by a suitable thermodynamic model for the solar chimney and an electrical model for the PV-based fan. The comparison was performed fixing the solar incidence area. Results of the simulations show the case of the PV-powered DC fan supplies an air mass flow rate three times higher with respect to the case of the solar chimney. Thus, PV-powered DC fan overall efficiency is two orders of magnitude higher than the one of solar chimneys.

Building energy consumption can be reduced using a plurality of approaches, such as: increasing the utilization of renewables, improving building envelope performance, improving the efficiency of the heating and cooling systems. All these energy efficiency actions often require relevant investments and a major refurbishment of the buildings. However, the energy consumption may be also significantly reduced by optimizing the energy management system. In fact, in many cases up to 50% of the total input energy is dissipated by inefficient energy management system. Therefore, the development of efficient, robust and reliable control management system is crucial in order to achieve the goals in terms of buildings primary energy reduction. In this framework, Cottafava et al. [186]

proposed a novel tool to be used in the energy management of large building stocks, which is capable to detect anomalies due to abnormal energy use. Their approach is not based on complex thermodynamic dynamic simulations of the buildings and their HVAC systems. Conversely, they implemented that data visualization approach (DataViz) coupled with the Multidimensional detective approach, using the Scatter Plot Matrix and the Parallel Coordinates methods. Then, a clustering algorithm was implemented in order to analyze the data. A case study as discussed for the buildings of the University of Turin, Italy. This method allowed one to identify some outliers, detecting the buildings with abnormal energy consumptions. High specific energy consumption are due both to large IT centres and to electric chillers running 24/7. Then a clustering algorithm was used to test the initial hypothesis. This approach revealed that a number of buildings should be reorganized according to different clustering categories.

Oluleye et al. [187] investigated the utilization of thermal energy storage systems (TES) in dwellings. TES are becoming more and more crucial in the present energy system where the management of excess heat is a key point in order to achieve a good economic profitability. However, authors pointed out that no specific funding policy is available for TES to be used in buildings. Therefore, authors presented a novel optimization technique based on a multi-period MILP in order to integrate TES in an existing dwelling. The optimization procedure aimed to minimize the Equivalent Annual Cost (EAC) of a micro-CHP system including a suitable TES. The model considers, for each time step, the performance parameters of the devices and the present energy market prices. Results of the optimization significantly depend on the house type: highest advantages are calculated for a detached house. In this case, the integration of TES in a micro-CHP system reduces the TDE by 792 kWh/year, CO<sub>2</sub> by 146 kg/year and the homeowner makes 60 £/year. From the economic point of view, results showed that this technology needs to be supported by incentivization, also based on the achieved CO<sub>2</sub> reduction. In the non-incentivised case, TES showed a better economic performance with respect to the micro-CHP system.

### 3.6. Other Topics

Li et al. [188] performed a numerical thermo fluid dynamic simulation of packed beds with smooth or dimpled spheres featured by low channel to particle diameter ratio. Such devices are widely used in a plurality of applications, for example catalytic reactors and nuclear reactors. Several types of packed beds are under investigation, such as the composite structures packing which allows one to dramatically reduce pressure drops with respect to the randomly packed beds. In this framework, authors analyzed the influence of a series of dimpled spheres in wall bounded structured packed bed from the thermo fluid dynamic point of view. Two different low channel to particle diameter ratios ( $N = 1.00$  and  $N = 1.15$ ) were considered. The analysis is performed implementing a suitable computational fluid dynamics model, developed in ANSYS FLUENT environment, taking into account 3-D Navier-Stokes equations for steady state incompressible flow and assuming the RNG  $k-\epsilon$  model. The simulations were performed considering two different low channel to particle diameter ratios ( $N = 1.00$  and  $N = 1.15$ ). The results of the simulations showed that, for  $N = 1.00$ , the packed bed with dimpled spheres should be used in real applications to enhance the performance, due to the lower pressure drops and higher heat transfer coefficient. In addition, for  $N = 1.15$ , pressure drop significantly increased. Thus, the packed bed with dimpled spheres should be used only when the need to enhance heat transfer performance dominates the problem of pressure drop increase. Sun et al. [189] designed a path tracking steering controller for autonomous vehicles. Autonomous vehicle is a new challenging technology which aims to increase driving safety, reduce traffic congestion and emissions and to improve vehicle overall efficiency. In order to achieve these goals, the vehicle must accurately track the desired path. In particular, this paper presents a model predictive control (MPC) using a linearization method. The vehicle model is linearized by a sequence of supposed steering angles. This model was also coupled with linearized single-track 'bicycle' model and a brush tire model to simulate the high speed motion of the vehicle. A simulation has been performed to validate the

accuracy of the method. Results indicates show that the steering controller with course-direction deviation reduces the average of absolute lateral deviation, compared to the controller with heading deviation, by nearly 20%.

Borjigin et al. [190] investigated longitudinal heat conduction in plate heat exchangers. A number of techniques are available in the open literature for the design and simulation of plate heat exchangers (LMTD, NTU, etc.). All these techniques are based on the assumption that longitudinal heat transfer can be considered negligible. However, in the present paper authors implemented a suitable numerical model in order to analyze the feasibility of such assumption for a small-scale plate heat exchanger. The model was implemented for a gas-to-gas plate heat exchanger, used in a cabinet cooling system. The system includes hot and cold fluid channels which are separated by two solid plates. The model is based on 3D steady state mass, energy and momentum balance equations. Both fluids are considered incompressible and turbulent flow is assumed. The developed numerical code was suitably validated using literature data. Results showed that longitudinal heat is not negligible and in small-scale counter-flow plate heat exchangers a more uniform temperature profile is achieved with respect to the case of negligibility of longitudinal conduction. In balanced cross-flow and parallel-flow plate heat exchangers longitudinal conduction is negligible. In unbalanced flow, the small-scale longitudinal heat conduction is low for all types of heat exchangers. Finally, authors also concluded that the higher the thermal conductivity of the plate, the stronger the small-scale longitudinal heat conduction and the larger the thermal performance reduction.

#### 4. Conclusions

This special issue of *Energies*, dedicated to the 12th Sustainable Development of Energy, Water and Environment Systems Conference, held in 2017 in Dubrovnik, Croatia, provided an insight of topics related to sustainable development. The guest editors of this special issue believe that the selected papers and addressed issues will be extremely interesting for the readers of *Energies*. The selected papers present recent advances in five main fields that are of strategic importance to the sustainable development: energy policy and energy efficiency in smart energy systems, polygeneration and district heating, advanced combustion techniques and fuels, biomass, building efficiency.

The papers included in the present special issue, and the ones previously published in past SDEWES SIs, clearly show that an integrated approach is required in order to achieve the goals in terms of sustainability and decarbonization, mentioned several times in the papers of this SI. First, a suitable energy planning is mandatory required in order to design the future energy scenarios. In this framework, it is also extremely important to design suitable funding policies to support the novel clean technologies, such as: fuel cells, electrical vehicles, hydrogen, etc. In addition, a special effort must be also performed in order to enhance energy efficiency and to promote system integration. It is extremely important to integrate different technologies in novel efficient polygeneration system, mainly based on renewables. Similarly, it is also crucial to recover all the energy flows which are presently wasted or dissipated. In terms of energy efficiency, a key role is due to the buildings which account for about 40% of the overall energy consumption. Thus, suitable energy saving actions must be performed for building envelope and its heating and cooling systems. Obviously, the goals of efficiency and sustainability can be achieved only in a future scenario where the use of renewables will become dominant over the fossil fuels. Solar, hydro and wind are very important in several countries. However, they suffer for unavoidable fluctuations and unpredictability of power production. Conversely, the use of biomass is much more efficient from this point of view. As a consequence, a huge research effort has been developed in order to select clean and sustainable novel biomass conversion techniques (algae, bioethanol, biorefineries, etc.).

Future SDEWES conferences will further contribute in disseminating new knowledge pursuing the goal of sustainable development. Readers may refer to the International Centre for Sustainable Development of Energy, Water and Environment Systems (SDEWES Centre) for additional information regarding the conference series and the related activities.

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