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Review

Recent Advances in Technologies, Methods, and Economic Analysis for Sustainable Development of Energy, Water, and Environment Systems

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Abstract: Sustainability has become a broad societal goal, aiming to ensure that human beings coexist safely and harmoniously with nature over a longer time. The influence of the COVID-19 pandemic on the global economy is coming to an end. The development and merits of sustainable energy supply, advanced technology, and economic features have received significant attention over the last few decades. However, significant gaps still exist with respect to how to design, construct, and implement hybrid and optimal energy systems with the lowest investment and cost. Since 2002, the Sustainable Development of Energy, Water, and Environment Systems (SDEWES) conferences have become a significant meeting venue for researchers to introduce, discuss, share, and disseminate novel concepts and ideas. This paper presents an overview of published articles in the Special Issues (SIs) dedicated by the series SDEWES conferences, especially those published in *Energies* recommended by the 16th SDEWES Conference, which was held on 10–15 October 2021 in Dubrovnik, Croatia. This SI in *Energies* focused on four main topics, including the application of renewable bioenergy, component enhancement in renewable systems, sustainable development for buildings and economic analysis and evaluation for sustainability. The collected papers provide insight into the topics related to recent advances in improving sustainable efficiency, including studies on waste-to-wealth techniques, utilization of hybrid bioenergy systems, heat exchangers and other components for performance enhancement, energy supply and demand analysis, low-temperature DHC systems, techno-economic assessment, and environmental evaluation.

Keywords: bioenergy; hybrid system; district heating and cooling; economic assessment; environment evaluation

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1. Introduction

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

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

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

The literature presented in the present review is mainly cited from research presented in the past SDEWES conference series. This paper is structured as follows based on the Special Issue in *Energies*. Section 2 collects papers that address the topic of bioenergy application, especially focusing on waste-to-wealth techniques (e.g., woody biomass [10], cooking waste oil [11], etc.) and hybrid bioenergy systems (e.g., heat and power plant with thermal and battery energy storage [12]). Section 3 reviews component enhancement in renewable systems, including heat exchangers (e.g., cooling and thermal recovery devices for photovoltaics [13]) and other components for renewable applications (e.g., scroll expander for ORC [14], nozzle for compressible systems [15]). Section 4 collects papers that address the topic of sustainable development for buildings, including energy supply and demand analysis (e.g., sediment heat energy [16], lifecycle analysis [17]) and low-temperature direct heating and cooling (DHC) systems [18]. Section 5 collects papers that address the topic of techno-economic assessment of renewable systems (e.g., energy storage systems in microgrids [19] and smart control for hybrid renewable energy resources [20]) and environmental evaluation (especially for individual mountain huts [21] and building retrofit [22]). Eventually, Section 6 summarizes the main conclusions of the present review and the limitations of the current investigation.

2. Application of Renewable Bioenergy

2.1. Waste to Wealth Techniques

Bio-energy is regarded as one of the most applicable candidates for the replacement of conventional fuels [23], indicating viable energy innovation for globally sustainable development. Chai et al. [24] reviewed the recent development of biomass waste-to-wealth conversion using the supercritical fluid extraction technique, which can transfer biomass waste to value-added products for commercialized applications, such as bio-oil [25], bio-gas [26], phenolics [27], biopesticides [28], etc.

Biomass is regarded as one of the most CO_2-neutral fuels, showing a significant contribution to green-house gas emission reduction by substituting fossil fuels [29]. Esteves et al. [30] proposed a multi-objective optimized methodology coupled with the support of the lifecycle assessment framework. Greenhouse gas emissions and energy balance were regarded as two lifecycle performance metrics. Results showed that soybean biodiesel has greater energy potential than biogas and bioethanol, which generated lowest greenhouse gas emissions per kilogram of biofuel. Mancusi et al. [31] studied a multiple interconnected fluidized bed system for the chemical looping combustion (CLC) of solid bio-fuels, aiming to recover CO_2. The hybrid energy from various renewable sources, such as photovoltaic panels and wind turbines, was considered to be collected in the CLC processes. It was noted that the electric energy conversion efficiency of the hybrid system could reach about 30%, a value that far exceeds the value evaluated for a similar power-to-methane-fed system. It was predicted that, compared to the production of methane, the synthesis of the methanol-producing process is much more effective with respect to the electric energy storage efficiency. Kamizela et al. [32] provided the biomass factory concept to establish a technological system, which consisted of sewage microfiltration, conditioning, and cellulose material sludge in a wastewater treatment plant. The lifecycle assessment (LCA) of a wastewater treatment plant showed that the net CO_2 emissions were reduced by 5.8 kg CO_2 per 1 t of wastewater. Meanwhile, pronounced benefits of changing the eutrophication potential by 1.7 to 2.0 kg of N_2O and 2.78 to 3.0 kg of PO_4 per 1 t of wastewater can be achieved. In developing countries, biomass is also generated from natural and domestic waste, transferring traditional, inefficient, and unsustainable methods to environmentally friendly, energy-saving, and low-carbon methods [33]. More sufficient and sustainable utilization of bioenergy may significantly lower pollutant emission levels [34]. Tesfamariam et al. [35] evaluated the nitrogen fertilizer value of biosolids from wastewater using post-treatment dewatering biosolid treatment technologies. The highest nitrogen release per unit ton of biosolid applied reached 24 kg for the activated technique, which was 6 kg higher than for the anaerobically digested biosolid technique. Hence, the selection of an appropriate biosolid treatment and dewatering technique is key to improving the fertilizer value of biosolids. Cavaignac et al. [36] carried out an environmental and techno-economic analysis of biogas upgrading processes using Aspen Plus. Acid gases such as CO_2 and H_2S could be removed from municipal solid wastes, and the upgrading process significantly increases the heat combustion value of the final product and simultaneously reduced air pollutant emissions. Results indicated that the diglycolamine-based upgrading route could generate a biomethane product with 91% methane, removing up to 99% of CO_2. Using LCA, a further reduction of 95% in CO_2 equivalent emissions was reached.

Woody biomass power plants were rapidly constructed all over the country after the feed-in tariff scheme began [37]. Tabata et al. [38] discussed the positive and negative impacts of using woody biomass on economic, environmental, and social systems and ecosystems. It was noted that the annual expenses may increase, which is a positive impact because of its contribution to the economy and employment in the region due to the increase in the production value. However, the influence on the local natural ecosystem showed a negative impact when the woody biomass was not appropriately utilized. Meanwhile, the wastewater treatment and post-treatment drying techniques also play a crucial role in the fertilizer value of biosolids [39]. Benić et al. [10] investigated the potential use of a novel direct driven electro-hydraulic system for articulated forestry tractors (skidders), considering the significantly high energy efficiencies of such systems with respect to the classical electro-hydraulic systems. The skidder studied in this work, as shown in Figure 1 pulling two logs simultaneously, is the EcoTrac 120 V, made by the Croatian company Hittner in the town of Bjelovar. It is a seven-ton skidder equipped with a double drum winch. A comprehensive analysis of the skidder rear plate mechanism was performed, and static force profiles of the hydraulic cylinders were achieved for the rear plate based on measurement data from the literature and the mechanism dynamics. Both the classical and the direct driven electro-hydraulic systems were experimentally verified for the purpose of a comparative analysis of their efficiency. Experimental analyses were carried out under laboratory conditions for different hydraulic cylinder loading scenarios, including an unloaded cylinder case and several cases of different cylinder payloads. The results were utilized to achieve insights regarding the potential advantages of the directly driven electro-hydraulic system from an energy efficiency point of view with respect to the use of traditional proportional hydraulic systems. In fact, according to these results, an estimation of the skidder fuel consumption and possible fuel savings over the entire life span of the vehicle for a realistic vehicle utilization scenario was performed. The comparison of the classical system and the proposed one is reported in Table 1. The main result is that fuel consumption can be reduced up to five times in the case of the direct driven hydraulic system, with a yearly fuel saving of 85.05 EUR. Thus, the proposed system reaches the break-even point (return-of-investment point) in 4.12 years if a price difference of 350 EUR between the classical and the proposed system is not exceeded.

Figure 1. Skidder EcoTrac 120 V in operation.

Table 1. System fuel consumption.

	Ein (kJ)	Fuel Consumption (L)	Lowing/Lifting Cycles per Day	Workdays per Year	Fuel Price (EUR)
Classical system	80	0.0056	54	250	105.84
Direct driven electro-hydraulic system	16.2	0.0011			20.79

In recent years, studies regarding the recovery of waste oils from biodiesel fuels hve increased in the literature. Plata et al. [11] examined the effect of the proprieties of cooking conditions on selected properties of biodiesel produced from palm-based waste cooking oils (WCOs). In particular, the proprieties considered to affect the biodiesel proprieties were the cooking temperature, time of use, and length of reuse. Data on the cooking conditions employed at each restaurant were obtained using a quick survey completed by the owners of the restaurants. Various WCOs obtained from several restaurants in Bucaramanga, Colombia were considered: (i) fried chicken restaurants (FCRs), (ii) fast food restaurants (FFRs), (iii) snack producers (SPs), and (iv) typical restaurants (TRs). The biodiesel yield, kinematic viscosity, calorific value, and cetane number were evaluated for the different restaurants where the oils were collected. The reactor used for biodiesel production, including (1) a methanol/KOH mixture container, (2) reflux condenser, (3) heating bath, (4) temperature controller, and (5) magnetic stirrer, is shown in Figure 2. The results show that the palm-based WCO showed better proprieties than the other WCOs, achieving up to a 95% improvement in the biodiesel yield. However, the biodiesel yield might have been reduced by changes in the cooking temperature and the length of reuse was affected by the kinematic viscosity. On the other hand, the calorific value was unchanged as long as the cooking condition was significantly changed. Compared to petrodiesel, the cetane number decreased when the use and reuse decreased. The proprieties were as follows: yield: 93.1 +/− 0.2%; kinematic viscosity: 5.0+/− 0.3 mm^2/s; calorific value: 39.9 +/− 0.1 MJ/kg; density: 919+/− 9 kg/m^3; and cetane number: 67.4 on average.

Figure 2. Experimental system reported in [11], including (1) a methanol/KOH mixture container, (2) reflux condenser, (3) heating bath, (4) temperature controller, and (5) magnetic stirrer

2.2. Hybrid Bio-Energy Systems

There is an increasing awareness of examining the aspects of biofuels and combined biomass and other renewable energy sources in relation to the process of the sustainability framework [40]. The utilization of hybrid bioenergy systems has been gaining attention as a comprehensive framework for diagnosing, optimizing, and improving comprehensive designs.

Sivri et al. [41] experimentally investigated the effect of fuel composition, hydrogen addition, and the swirl number on the combustion efficiency and emission characteristics of various biogas mixtures. Based on the gas composition, both the radial and axial temperature distribution of tested biogas mixtures varied significantly with the hydrogen addition. A non-monotonous dependence on the swirl number outside the flame region was found because of the modified flow characteristics. The CO_2 emissions were also non-monotonous dependent on the fuel composition. Samir et al. [42] presented a comprehensive assessment of two butanol production biorefineries, involving sensitivity, techno-economic, and exegetic factors. Aspen Plus software was applied to construct the biorefineries, revealing reasonable evaluations of the production capacity, biomass feed flow, net present value, and return on investment. Cirillo et al. [43] presented a numerical model to predict the performance of a fixed-bed micro-cogeneration biomass gasification system coupled with a spark-ignition internal combustion engine. The performance of the system was linked to the main gasifier and engine parameters. The global electrical error predicted by the model could be controlled within 0.5% while the prediction of the thermal efficiencies away from the measured values was reduced to be within 4.0%. The consistency of the multi-component thermal properties may significantly affect the system efficiency. Bietresato et al. [44] investigated the kinematic viscosity of fuel blends with diesel oil-biodiesel-bioethanol and its effect on engine performance. It was noted that the viscosity of the mixed bio-fuel progressively increased by 38% at 40 °C while the biodiesel percentage ranged from 0 to 100%. It was suggested that a preheater should be installed in the fuel-feed system. The preheater might obtain the same fuel viscosity of the blends as the pump diesel oil and that the bioethanol fluidizes the blends, reducing the viscosity by about 2% per percentage point of bioethanol in the blend. Safe handling and utilization of bioenergy to avoids risks such as fires and explosions has come into focus in recent years. Manic et al. [45] presented an innovative thought for assessing the ignition risk and provided a ranking of the ignition risk for biomass fuels. Their results provided relatively accurate, simple, and quick determination data necessary for the design and application of appropriate measures to reduce fire and explosion hazards related to the operation of biomass. In recent years, the CO_2 storage and CO_2-enhanced oil and gas recovery in shale reservoirs has received significant attention [46]. Jia et al. [47] proposed a methodology for analyzing variations in the shale gas permeability during the production process, considering the impact of pore size reduction, the adsorption layer, and non-Darcy flow components simultaneously. Results showed that the geo-mechanical effect significantly reduced the intrinsic permeability of shale gas. Due to a lack of studies on the CO_2 storage capacity in shale reservoirs under a wide range of pressure, the CO_2 flow behavior in shale reservoirs was investigated [48], illustrating an important impact on both the improvement in CO_2-related oil recovery and enhancement of gas recovery and carbon sequestration. Then, they [49] further measured the high-pressure CO_2 adsorption in low, middle, and upper Bakken shales. It was confirmed that the nuclear magnetic resonance is eligible for tracking the fluid movement before and after CO_2 exposure in shales, and the most important impact factor is the adsorption outweighing the molecular diffusion, which may determine the CO_2 injection rate. With the development of artificial intelligence techniques, bioenergy systems can be optimized automatically, revealing more effective progress based on existing experimental and numerical data [50].

David et al. [51] modeled the bio-fuel gasifier model using the inbuilt biogas power plant modules in HOMER software. An electric generator, through the syngas produced in a downdraft biomass gasification plant, was simulated while both technical and economic parameters were included. A case of isolated rural communities in Honduras and Zambia was studied. Results showed that the energy supply demand and energy distribute demand by the microgrid had a levelized cost of energy, which is lower than the scheme of extending the electric grid to the communities. Juan et al. [52] developed a multi-objective target-oriented robust Monte Carlo model to optimize a biomass co-firing network, integrating uncertainties in the biomass properties with investment and operations planning. Compared to the deterministic solution, the robust optimal network had a relatively insusceptible influence on the uncertainties. Bedoic et al. [53] developed a robust optimization model with the objective of minimizing the total costs. Linear programming, considering the market price of electricity, was coupled in a mathematical model, which was tested in a 1 MWel installed biogas power plant. The economic analysis showed that an improvement in the feedstock gate fee of 100 €/ton may result in a significant decrease in the production costs of renewable methane of 20–60%, showing significant economic viability. The robust model also indicated that the uncertainties related to electricity production from wind and photovoltaics amy increase the cost of gas production by 10–30%. Bartolucci et al. [12] presented a study regarding the data-driven optimal design of a combined heat and power (CHP) plant for a hospital building. The proposed methodology allows one to simultaneously optimize the economic and environmental performance of the considered CHP plant coupled with the anaerobic digestion (AD) process of spent coffee grounds using biogas for co-burning or completely substituting the fossil methane to fuel the CHP unit. The effects of integrating energy storage technologies, such as thermal energy storages and battery energy storage systems, were investigated. Optimization of the plant was performed using a bi-level optimization approach applied to a real application consisting of a large Italian user in Rome (Italy), the Tor Vergata Hospital. In fact, CHP power plants are often used for hospital users due to the significant and simultaneous thermal and electric energy demands. In particular, this hospital includes a 350 kW NaBr absorption solar cooling plant, 100 kW PV panel field, and a 2 MW CHP plant based on a reciprocating internal combustion engine (ICE) fueled by natural gas. Considering the historical data of the electric and thermal energy demand of the hospital, a clustering analysis was applied in order to identify specific load patterns representative of the annual load. These patterns were used as input data in the design procedure. A genetic algorithm coupled with mixed integer linear programming was used to optimize the size of the CHP plant and energy dispatch, respectively, with the aim of minimizing the carbon emissions and total costs and maximizing the primary energy savings. The results of this particular approach highlight that proper design of combined heat and power plants is useful for achieving a CO_2 emission reduction of about 10%, with economic savings of up to 40%, when the proposed CHP plant is compared with a system with the conventional separated production. Additional environmental benefits can be achieved by means of the integration of anaerobic digestion and energy storage, increasing the CO_2 savings up to 20%.

3. Component Enhancement in Renewable Systems

3.1. Heat Exchangers in Renewable Systems

It should be noted that the higher energy efficiency of renewable systems can achieve greater eco-sufficiency and energy conservation [54]. Due to the dramatically growing energy demands, sustainable development has become imperative, especially for industrial progress [55]. In this regard, the efficiency improvement in renewable systems has become a critical concern [56]. The application of heat exchangers (HXs) has a pronounced effect on energy saving and thermal energy integration [57].

The structural optimization, orientation arrangement, and change in the working conditions of HXs can effectively improve their thermal performance [58]. Holic et al. [59] investigated the application of a waste heat recovery unit for the recovery of waste heat through the Rankine cycle and organic Rankine cycle, which was installed between the exit of the engine and the exhaust cooling heat exchanger. A multi-objective thermo-economic optimization procedure was proposed and applied. For the case with exhaust gases of 1.77 kg/s at a temperature of 410 ◦C, the electrical efficiency could be improved by 2.97% and the investment payback period was reduced to 6.8 years. Tian et al. [60] proposed a shell-and-tube heat exchanger with a moving packed bed with elliptical tubes, which could significantly reduce the cavity zone and stagnation zone in conventional shell-and-tube HXs. The results showed that the heat transfer coefficient at the top and the bottom could be improved by an average of 42% and 53%. The heat transfer in the inside tube was increased by 5% to 29%. Meanwhile, the flexural capacity was simultaneously improved by 8% to 36% when the new HXs were applied. Lian et al. [61] proposed a hybrid printed circuit heat exchanger (PCHE) with a comprehensive flow channel design, which can significantly enahcne the thermal performance. In comparison to conventional PCHEs, the core volume could be reduced by 49% at the same thermal load, equivalent to a 145% improvement in the heat transfer rate per unit volume. Ma et al. [62] studied the local heat transfer performance of PCHEs under rolling conditions. It was reported that rolling might improve the heat transfer by 25% while jeopardizing the pressure drop by 75% using trans-critical natural gas. However, the maximum Nusselt number could be raised by 40% with a minor change in the pressure loss in the subcritical zone under the rolling condition. For natural gas flowing under pseudocritical conditions, the maximum Nusselt number could be improved by 15%. Zheng et al. [63] investigated the performance of a plate heat exchanger when dispersing 20-nm-diameter Fe_3O_4 spherical nanoparticles. It was indicated that the Nusselt number can be enhanced by an average of 21.8% when two magnets were vertically arranged side by side. Compared to the case without spherical nanoparticles, a pressure drop with a 10% reduction could be achieved.

Despite the improvement in the physical parameters, the application of artificial intelligence and topology modification to the new HX design and optimization has also shown a notable effect and good payback. Li et al. [64] deployed a network retrofit and constructed a network topology modification strategy for heat transfer enhancement of HXs. They proposed a target evaluation methodology, which considers the thermal efficiency, pressure drop, and level of heat transfer enhancement simultaneously. It was found that the best design of HX can achieve a significant improvement in the economic efficiency and energy savings. Moreover, fewer modifications based on the original existing heat exchangers were executed. In one case study, the energy saving rate was 10.6752 MW, displaying a 13.3% improvement in the heat transfer rate. Age is negatively correlated with HXs' performance and efficiency. Chin et al. [65] constructed a mixed integer linear programming (MILP) model to evaluate the economic performance and decide whether to upgrade the heat exchangers or purchase new heat exchangers. This method integrates the HX lifetime, reliability functions, investment, and maintenance to visualize the benefit of hybrid processes. The results showed the 20 years is the planning horizon. Then, Zirngast et al. [66] presented an modified method named mixed integer nonlinear programming (MINLP) synthesis to search for the best design variable parameters of a flexible heat exchanger network. The MINLP was based on a large number of databases with uncertain parameters, and it was eligible for simplifying the complicated searching problem, with the size variable remaining independent of the number of parameters. Results showed that the implementation of the synthesized MINLP in heat exchanger optimization could reduce the search time and improve the optimal result by 7.6%.

A multiscale approach can also be applied to HX design in heat recovery systems, e.g., district heating [67], photovoltaic systems [68], and combustion engines [69]. Moita et al. [13] addressed two heat recovery systems for two macro-applications: (i) cooling of a PV cell, where the subtracted thermal energy is used for desalination purposes; and (ii) the recovery of thermal energy from exhausted gases with the application of innovative heat pipes associated with the thermoelectric generator. The authors presented experimental results, including temporal resolution, visualization, high-spatial thermography, and flow hydrodynamics. Both discussed recovery systems illustrate the potential of the application of two-phase flows. However, the instabilities should be accurately addressed for microscale applications. The most significant contribution was the proposal of comprehensive and innovative flow analysis to optimize the channel structures, displaying high-speed visualization with time-resolved thermography. The main results achieved from these experimental tests demonstrate that a significant improvement in the dissipated power could be achieved using the microchannel-based heat sink at the expense of controlled pumping power. In addition, compared to existing systems, promising results were achieved by the application of the proposed thermal control strategies. The high-efficiency operation of thermoelectric generators under highly fluctuating thermal loads could be explained as a high usability was reached due to the available exhaust heat.

3.2. Other Components for Renewable Applications

Renewable energy systems frequently operate in off-design conditions [70]. Generally, the application of volumetric-type machines and their capacity could overcome the concerns regarding time-varying fluid thermodynamic properties [71]. On the other hand, it is also crucial to consider the proper design and selection of expanders to successfully overcome unsteady operation.

Fatigati et al. [14] investigated scroll expanders as novel technology to be integrated into a small-scale power unit with an organic Rankine cycle (ORC). This technology, in the case of small applications, operates in off-design conditions. The authors proposed a novel system named a dual-intake-port (DIP), with an intake port added to the main one. Modification of the expander permeability increased the flowrate in the ORC system, and the off-design conditions were also significantly improved without increasing the inlet pressure of the expander. The authors assessed the feasibility of DIP technology, which demonstrated that the novel solution is eligible for other volumetric expanders. In this regard, a comprehensive numerical model was further proposed with experimental validation. GT-SUITETM software was applied for the scroll expander modeling, allowing mono-dimensional (1-D) and zero-dimensional(0-D) integrated analysis. The prediction errors of the mass flow rate and mechanical power could be controlled within 2.6% and 6.7%, respectively, which is regarded as a trustable prediction method for assessing the DIP feasibility. The position and geometry of the second port was optimized and a comparison with the baseline system was carried out and the singe-intake-port was assessed. It was reported that the introduction of the second port could provide an increase of 25% in the mechanical power and an increase of 37% in the mass flowrate when the optimized configuration was applied. With respect to the baseline machine, DIP technology produced an increase in the mechanical power of about 25%. As a result, the power was raise increased from 1131 to 1410 W with an unchanged pressure difference across the expander of 5.6 bar when the DIP technology was implemented. Meanwhile, the DIP scroll showed a higher efficiency than the DIP SVRE case, 50–60% vs. 40%.

On the other hand, the design of the header may affect the flow distribution and mixture uniformity in the core component [72]. Fadzil et al. [73] developed a novel centralized water reuse header. When two units of headers were applied, consumers were eligible for benefits of 50.9% in cost savings in freshwater and an 89.6% reduction in wastewater. Wołosz [15] presented the development of detailed energy analysis of an industrial nozzle. Due to the nonuniform distribution of the energy flux across multi-channels, the nozzle efficiency was analyzed. The OpenFOAM® toolbox with the finite volume method (FEM) was applied to determine the gas energy magnitude and flow parameters. Figure 3 illustrates the visualization system with one nozzle, which is the investigated object. Moreover, the loose material, inlet head, and pressure accumulator were also considered. The cross-sections of the nozzle and the flow channels are also shown with the possible direction of the impact. The results showed that less exergy and lower energy rates were delivered at the inner channel compared to the others. Meanwhile, the corresponding increases in the pressure and temperature were rarely translated to the loose material. A significant decrease in exergy was recognized due to the high gas flowrate in the inner channel. Furthermore, significant fluctuations resulting in energy peaks might occur when gas flows during the working cycle. Thus, the nozzle effectiveness remains at a low level due to the disadvantageous structures in the loose materials.

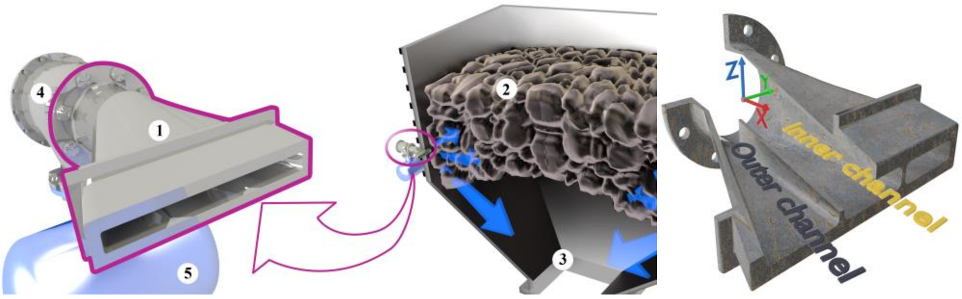


Figure 3. Visualization of the pneumatic pulsator system: inner and outer channel, including (1) nozzle, (2) loose material, (3) silo, (4) head, and (5) pressure accumulator.

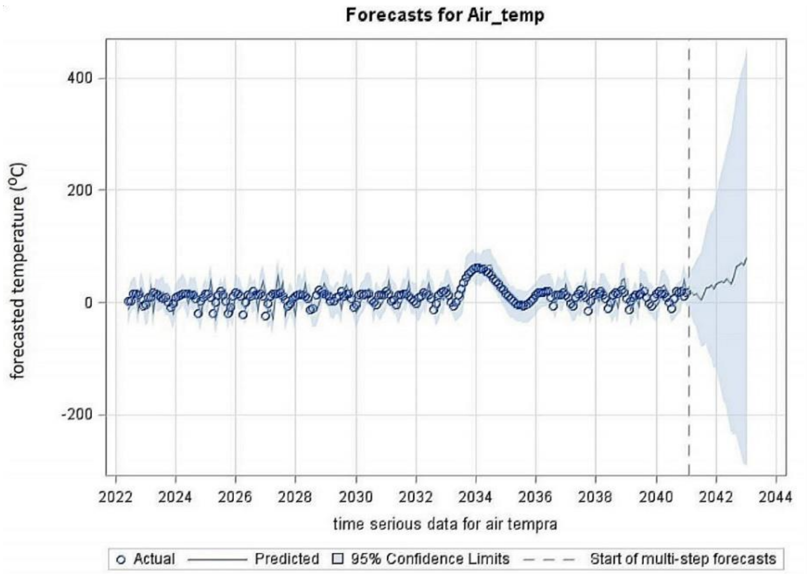
4. Sustainable Development for Buildings

4.1. Energy Supply and Demand Analysis

For national and regional primary production of energy, the analysis of the energy supply and energy demand should be forecasted using current and historical data, which might promote a decrease in the wholesale electricity price [74]. A good prediction model has now become a necessary and powerful tool for monitoring and modeling energy supply and consumption patterns [75]. The fast regulation and control of the overall energy demand simultaneously alleviates the supply chains for coal and natural gas, and might also increase the flexibility of sustainable energy resources [76].

Quaggiotto et al. [77] focused on the heat supply in comparison to the heat distribution side. They developed a predictive control strategy based on mixed integer linear programming (MILP) optimization to schedule the heat supply from cogeneration plants, heat pumps, and gas boilers as a function of the consumer heat load, waste heat production, and electricity price. The proposed strategy could achieve a pronounced reduction in operational costs of about 5.8–12.5% in a middle and winder season. The utilization of a centralized heat storage tank could further increase the flexibility of the system connected to heat pump units while the cost could be improved 6.3–20%. Pursiheimo and Rama [78] studied a residential area with 16 buildings using an hourly linear optimization model. The average annual heat consumption reached 5.6 GWh with the local district heating network. When a distributed renewable energy supply with separation from the district heating supply was applied, the annual total costs may increase by 12–24%. Furthermore, complete removal of the distributed district heating network might increase the total costs considerably. Consequently, compared to solar collectors and exhaust air heat pumps, the application of a centralized ground source heat pump with heat storage showed more cost-efficient levels. Guillen-Lambea et al. [79] considered a residential district located in Spain. The lifecycle assessment (LCA) methodology was implemented within a mathematical model, and the objective function considered the minimization of environmental loads. Four optimal configurations were considered: a reference system with a gas boiler and split-type air conditioners, and then three thermal energy storage (TES)-based systems were tested. Regarding carbon emissions, latent TES with paraffin showed the lowest emissions, followed by sensible TES with water. Reductions in the energy demands compensated for the impact of paraffin, and the results of sensible TES were strongly dependent on the tank design. The wastewater entering the treatment facility also has a significant waste heat content. Zivkovic and Ivezic [80] focused on the mostly unused resource of sewage wastewater heat in Serbia. They proposed a methodology for estimating the technical potential of waste heat from wastewater treatment facilities for recovery in district heating via the application of a heat pump. A total of three indicators were applied, focusing on the energy performance of district heating systems, security of the energy supply, and environmental impact. It was estimated that the improvement in the primary energy savings, reduction in carbon dioxide emissions, and reduction in import energy dependency could be improved by 5%, 6.5%, and 9.8% annually, respectively, when the sewage wastewater potential was fully utilized. As a result, the diversification of energy sources could be improved by 21%. The demand for hot water accounts for up to 18% of the total final energy demand in buildings. Meha et al. [81] developed a spatial–temporal method for the annual hot water demand. Integrated demand maps for space heating and hot water and curves for the actual and potential demand for direct heating were developed in Kosovo. When estimating the temporal operation of district heating, demand profiles from an hourly to seasonal scale were considered, which could be reduced from 1.8 to 1.32 TWh/year. It was also estimated that for space heating, the maximal capacity would be around 600 MW and an additional 70 MW thermal capacity should be supplied to cover the hot water demand during the winter season.

The increase in temperatures due to climate change has been highlighted and can be considered a useful solution, mainly during the summer months [82]. Girgibo et al. [16] developed a study, aiming to utilize seabed sediment energy as a renewable heat source for building space heating purposes. The authors declares that the novelty of this work was due to the potential correlation between the use of seabed sediment heat collection and climate change. In this work, the authors aimed to examine and identify the appropriate correlation and define the shore distance at which there is maximum heat energy production. In total, 42 new houses in Suvilahti, Vaasa, were used as a case study, which were designed to be heated and cooled by the heat energy from the seabed sediment. The energy mainly originated from solar energy collected by heat collection pipes, which were installed in the seabed at a 3–4 m depth from the sea bottom. The pipe network was also applied to cool houses the during summer seasons. The air and water temperatures were measured using Statistical Analysis System (SAS) software with the Enterprise Guide 7.1 version. Specific correlations for the sediment temperature data were established. Based on the developed ARIMA model, it can be concluded that the air and water temperatures gradually increase. The sediment temperature showed a positive impact on the water temperature, with a lag of two months. In this regard, it is expected to increase the sediment heat energy in the coming future. The forecast results can be observed in Figure 4. It is noted that after 2041, the air temperature might significantly increase with the prediction trend. A significant decline in the snow depth will occur by 2033 due to the impact of global warming. Consequently, particular changes in the sediment temperature and corresponding heat energy production were found due to the above changes. The authors also demonstrated that the sediment temperature is expected to decline with snow melting due to the increase in the winter temperature.



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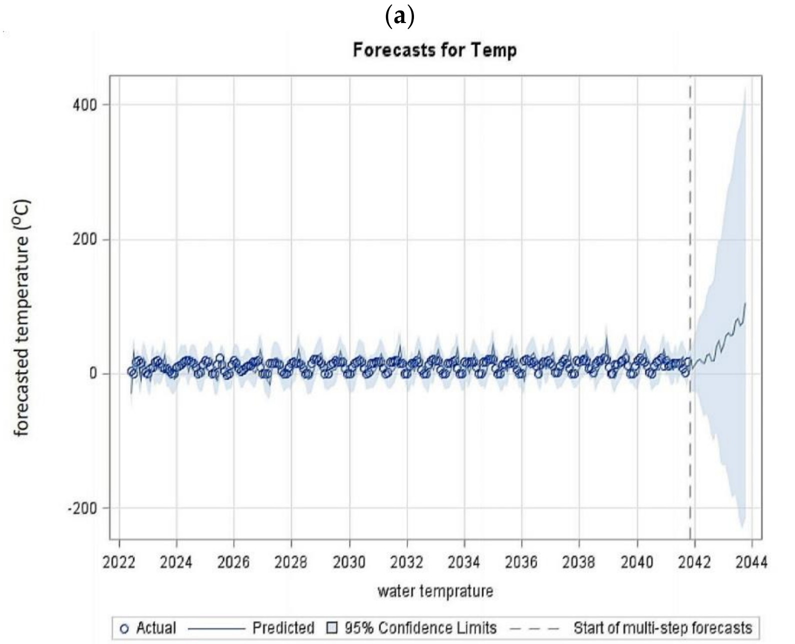

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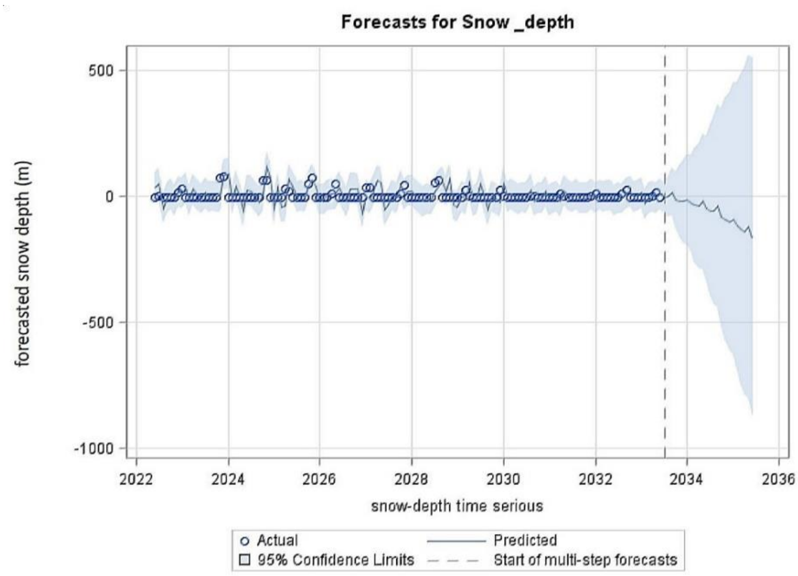

(**c**)

Figure 4. ARIMA analysis of the (**a**) forecasting of the air temperature from 2022 to 2044, (**b**) water temperature forecast from 2022 to 2044, and (**c**) forecasting of the snow depth from 2022 to 2036 in the Vaasa Airport weather station.

According to a lifecycle viewpoint, the cost optimum retrofit measures of the marginal cost difference method for buildings should be calculated. Then, the primary energy savings of each optimized measure can be estimated. Gustavsson and Piccardo [17] investigated the energy saving of conventional retrofit building materials, such as glass wool, aluminum, and rock materials, in comparison to wood-based materials. Lifecycle primary energy implications were introduced when wood-based materials were utilized instead of non-renewable ones. In particular, the economic analysis of these measures was evaluated via the defined indicator named the net present value. The measures of a lower U-value in new windows, varied insulation materials in external walls, and attic floor with extra insulation were numerically studied. A total of three different insulation materials, including wood fiber, rock wool, and glass wool, with A thermal conductivity of 0.038, 0.037, and 0.042 W/mK, respectively, were tested. Additionally, extruded polystyrene XPS was also applied to basement walls with a thermal conductivity and density of 0.030 W/mK and 32 kg/m^3, respectively. The cost and energy savings and the sensitivities of envelope retrofits were evaluated, assuming scenarios had a renewable-based district heating (DH) supply. The investigated building comprised 27 apartments. The total heated floor area and the ventilated volume were 4000 and 5200 m^3, respectively. It was noted that a total of 95–120 mm of mineral wool was covered by bricks and wood panels for insulation, and the heat-only boilers were implemented, including 3 wood pellet boilers, 2 boilers with flue gas condensers, and 3 oil boilers. The final energy consumption for space heating was calculated with and without the retrofit measures. The results showed that the energy cost savings were significantly increased by decreasing the U-value of the thermal building envelope. The case with the attic floor and basement walls displayed about a 16% cost saving and 83% energy saving compared to the case with extra insulation in the attic floor. In comparison to glass wool and rock wool, the lifecycle of wood fiber insulation might be reduced by 76% and 80%, respectively. A smaller-scale DH system showed much higher primary energy and cost savings.

4.2. Low-Temperature DHC System

Hybrid systems involving at least two energy sources can be adopted in various configurations and orientations based on energy sources and system scales [83].

Currently, the challenges in sustainable development and energy revolution include the applications of low-carbon and energy-efficient economies [84]. Fifth-generation district heating and cooling (5GDHC) networks have been proposed and optimized to meet the latest challenges of the recovery of low-grade energy [85], improve the energy supply efficiency [86], and reduce energy demands [87] while sustaining comfort standards.

Users coupled within a 5GDHC can showe interesting results in terms of the rational use of energy [88]. Bilardo et al. [89] developed an integrated model of a fifth-generation direct heating and cooling (5GDHC) network for buildings, providing users with different energy profiles throughout the whole year. A case consisting of 11 users with an annual energy need of about 79.2 GWh was tested and a hypothetical simulation scenario was proposed. The thermal efficiency of the network was assessed by a specifically defined index, which could be improved to 1.69, while the thermal integration level and the percentage weight of the electric need were 41% and 19%, respectively. Calixto et al. [90] modeled an existing neutral-temperature district heating network in which the distribution temperature almost approached the ambient temperature. This case, located in Ospitaletto, Italy, was studied with the application of decentralized heat pumps. The developed model was able to calculate the local operating parameters and regional network information levels within an execution time of 30 min. The approximate model was also developed by focusing on the energy balances aggregating all users with the concentrated demand.

Hiltumen and Syri [91] evaluated the possibility of recovering waste heat from data centers in a district heating system in Espoo, Finland. The influence of emission reduction on CO_2 emissions and the production costs was numerically investigated. Results indicated that the city's heating and cooling systems, with zero coal utilization, might significantly reduce the CO_2 emissions accompanied by a slight increase in the annual production costs. The reuse of waste heat could further reduce emissions, with prevention of an increment in the production cost. Kilkis [92] investigated a component oversize design versus a heat pump temperature peaking application for low-temperature waste energy or renewable energy resources. A higher exergy utilization rate of 23% could be achieved using the proposed exergy-based minimum carbon footprint model when operating at an optimum temperature peaking of 45 °C. The oversizing factor of the radiator reached 25%. It was concluded that this model is valid for environmentally, economically, and technically designing low-temperature heating systems for buildings. In a central European city, Matak et al. [93] integrated a heat and power waste incineration plant into an existing gas-based DHC. Results showed that the energy-from-waste potential in summer is 33% higher compared to the level in winter. Moreover, the heating demand showed an opposite trend. The amount of heat energy was compatible with the yearly energy required for the cooling demand. In this regard, the heat storage component played an important role due to the distinction between short-term heat production and demand.

In this regard, DHC systems that use fossil fuels and corresponding capacities are going to be closed down and replaced by renewable fuels [94], heat pumps [95], and waste heat utilization [96]. Caat et al. [97] explored the possibility of utilizing centralized district heating as a renewable alternative by introducing a rooftop greenhouse solar collector. Results showed that the extracted thermal energy could sustain up to 47 dwellings in an 850 m^2 greenhouse. It should be mentioned that the fossil-based electricity consumed by the greenhouse lights is lower than the equivalent natural gas consumption substituted by solar thermal energy, showing competitive energy savings to the direct heating strategy when reducing the daily photoperiod by 4 h (from 16 to 12 h).

Vivian et al. [18] investigated whether renewable energy communities could mitigate the high operating costs due to the electricity purchased by the grid for circulation pumps and heat pumps included in low-temperature district heating and cooling networks. The operating costs of these networks could be significantly reduced when the electricity was produced by local PV panels. The authors declared that the electricity self-produced and shared from local renewable plants for fifth-generation DHC networks has been investigated so far. Therefore, they aimed to cover this lack of knowledge using this approach, which is regarded as promising infrastructure to help decarbonize building sectors by introducing renewable energy communities.

Several economic and environmental indicators were assessed for a suitable case study represented by a group of 31 buildings (light blue in Figure 5) in the municipality of Montegrotto Terme (Italy), including a total of 7 non-residential buildings (including 2 office buildings, 2 schools, 2 religious buildings, and 1 shop), 10 mixed-use buildings (including 21 commercial units and 90 residential units), and 15 residential buildings. It is noted that the 30 buildings with red marks are potential members with assumptions.

The internal loads were defined based on the main end-use in the communities considering the schedules for the electric loads, occupancy, and ambient environment (including the indoor setpoint temperature, relative humidity, etc.). For further details, see the paper. The electricity produced by PV panels was calculated based on PVGIS modeling considering the weather conditions, the PV module efficiency, and its nominal efficiency. The radiation level on the module plane was also evaluated by calculating the diffuse solar radiation with the isotropic sky hypothesis, the beam solar radiation, and the reflected solar radiation with an albedo coefficient at 0.2. Four different scenarios based on the combination of the installed PV capacity and energy community members were compared, which are reported in Table 2. For cases with scenarios S2 and S4, the top celling of the PV power was set at 200 kW due to the current limit set by the Italian legislation. Results showed that the increase in self-consumption from distributed heat pumps could be lowered by 10% due to the seasonal requirement of the heating demand and PV production. For the same reason, the application of batteries also seems inconvenient. The environmental advantage of the proposed solution is evident. In fact, CO_2 emissions decreased by 72–80% with respect to the current situation depending on the installed PV power. Moreover, district-level PV sharing might significantly improve self-consumption when the installed PV power was increased by more than 45%. The results also suggest that the techno-economic performance of fifth-generation DHC networks should be further improved based on current incentives regarding PV sharing, indicating a viable option to develop renewable energy communities.

Figure 5. Map of the analyzed area in the Montenegro district of Italy (a group of 61 buildings).

Table 2. Summary of the simulated scenarios.

Scenario	S1	S2	S3	S4
Buildings in the REC	32	32	61	61
PV plants (-)	32	9	32	9
PV power (kW)	422	200	422	200

5. Economic Analysis and Evaluation for Sustainability

5.1. Techno-Economic Assessment

Technical investigations in terms of energy consumption, energy supply, emissions, and cost savings have been adequately exploited at present [98]. On the other hand, techno-economic analysis is also crucial for ensuring the feasibility of innovative business models [99], which can provide empirically practical theories to standardize the technological process [100].

Since significant limitations and bottlenecks were derived from previous scientific literature, Manfren et al. [101] addressed the critical role of techno-economic analysis and energy modeling in the next-generation energy service concept. It was identified that integration of techno-economic analysis and energy modeling processes is necessary, and envisioned that the development of eco-system interacting models could achieve an evolution of current practices and processes for energy transitions and decarbonization. Horvat et al. [102] proposed a mathematical model to execute appropriate strategies for renewable energy sources' utilization with profitability. Different control strategies were compared, comprising a thermal collector, heat storage, heat pump, and auxiliary renewable energy sources covering the electricity, heating, and cooling demand in a 180 m^2 family house. In typical days, results showed that the change in the operation strategy could reduce the operational cost according to the profiles of the energy demand, solar irradiance, and electricity price. Lamagna et al. [103] developed a MATLAB model to prove the economic advantages of the application of solid oxide fuel cells in civil environments such as hotels, offices, and hospitals. The internal return rate, payback period, and net present value were selected to evaluate the simulated scenarios while the energy saving, emission reduction, and electricity storage efficiency were considered. Noted that a pronounced emission decrease and energy self-sufficiency increase of 29% and 58% were achieved, and the economic payback period was estimated to be almost 3 years, which is close to its lifetime.

For a micro-grid system, the battery energy storage system is a fundamental component in micro-grid operations [104]. Strategies and scenarios for batteries, either based on the state of charge limitation or hybrid association with supercapacitors, have been presented [95]. Ndiaye et al. [19] presented a study regarding a technoeconomic analysis of energy storage systems included in microgrids in order to improve the energy management strategies. For this aim, detailed simulations of the microgrids were performed, presenting both the electrothermal and aging models of the storage components. The main contribution of this work regards the definition of a detailed management strategy, which takes into account the aging of storage systems in the real-time management of the microgrids, aiming to extend the lifetime of the storage systems. The presented management strategy also minimizes the installation costs whereas it optimizes the utilization of the battery. The results obtained in this work demonstrate the key role of knowledge of the aging processes of storage devices and the role of the techno-economic analysis to improve the operating cost and the energy management of microgrids. Figure 6 shows the studied DC microgrids, including PV panels, loads (buildings, electric vehicle charging stations), and storage systems (batteries, supercapacitors). The energy management system controller allows for connection to the public grid and provides voltage control, energy and power flow, load shedding, and load sharing. In this paper, the details of the electrothermal and aging models of lithium-ion batteries are presented. The electrical model of the battery is a Thevenin model, mainly comprising an OCV (open circuit voltage) source in series with the internal resistance. The cells used for the models and simulations are Samsung commercial cells with a nominal capacity of 26 Ah and the chemistry of NMC (nickel, manganese, cobalt) in the positive electrode and graphite in the negative electrode. The solar irradiation data used in the simulation were obtained from the PV installation of the Centre Pierre Guillaumat of the Université de Technologie de Compiègne (UTC), which consists of 16 panels in series with 130 W nominal. The control strategies investigated in this work were as follows:

(i) The classical microgrid energy management: considering the SOC of the battery, it is assumed that the extra power can be drained to the grid at any time;

(ii) The control strategy considering battery aging: this is an improvement in strategy 1. If the generated power is insufficient, the battery is not automatically used to supply the load, but the price per kWh from the grid is compared to the price per kWh, depending on the cost of the power electronics, batteries, and cost of integrated installation, step-up transformer, intelligent communication and controls, and grid interconnection to utility, replacement costs, repair and maintenance costs, and the discounted purchase price of the battery. The numerical results indicated that the battery life would be extended by 2.2 years, resulting in a pronounced reduction in the cost of batteries and the installation cost.

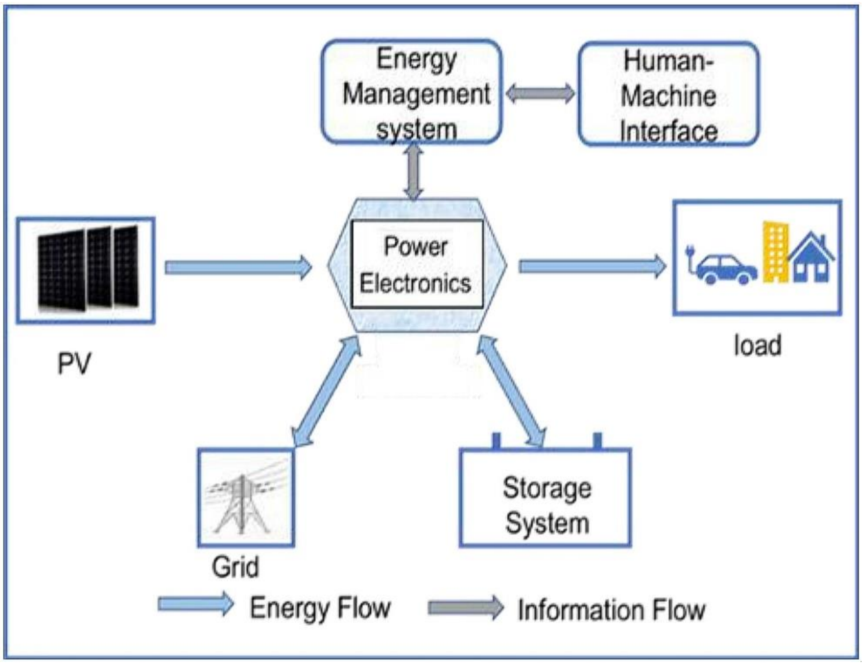

Figure 6. Microgrid layout.

On the other hand, the application of smart energy in public buildings is also a good alternative for achieving a higher energy efficiency, which should implement appropriate energy storage technology [105]. Salvia et al. [106] introduced the PrioritEE project to enhance the policy-making and strategic planning competencies of public building energy management in the Mediterranean area. Both soft tools and technical tools were executed, and a set of critical performance indicators were applicable and replicable in all European cities for promoting the application of renewable energy sources by local administration and improvement in the energy efficiency. The current energy performance of building stocks was easily assessed while different renewable interventions, ranks, and technical options were prioritized.

Herrando et al. [20] presented a study describing the development of an energy action plan as a key and useful element offered to local authorities based on energy-efficient measures and the integrated application of renewable resources in municipal public buildings. They also described the development of an energy plan referring to a decision support tool, database, and visualization platform, allowing local authorities to define suitable building renovation energy actions. This work considered the case study of Teruel province in the Autonomous Community of Aragón, located in northeast Spain. A total of 215 small municipalities were characterized, where rare technical staff were hired to make an energy plan decision. The authors highlighted that the availability of accurate building data is the most significant barrier due to the envelope features, thereby the decision support tool is required. Energy savings of 1.3 MWh/year and a CO_2 emission reduction of 245 tons CO_2e/year could be achieved when the proposed plan was executed. A total investment of EUR 1.2 M would be required. The payback time versus CO_2 emission reduction is illustrated in Figure 7. The bigger the circles, the larger the investment required. The results showed that the replacement of light fuel oil boilers with electric power input by biomass boilers was a more cost-effective measure with a payback time of 5–10 years. The replacement of current lighting systems with LEDs also involved the largest CO_2 emission reduction potential. However, the payback time would also be extended. Improvement in the envelope insulation was regarded as one of the most significant potential measures for reducing energy consumption, which basically alleviates the heating demand of buildings. However, it should be pointed out that the payback times of implementing envelope interventions could reach more than 10 years. Finally, window renovations have large payback times and lower energy savings

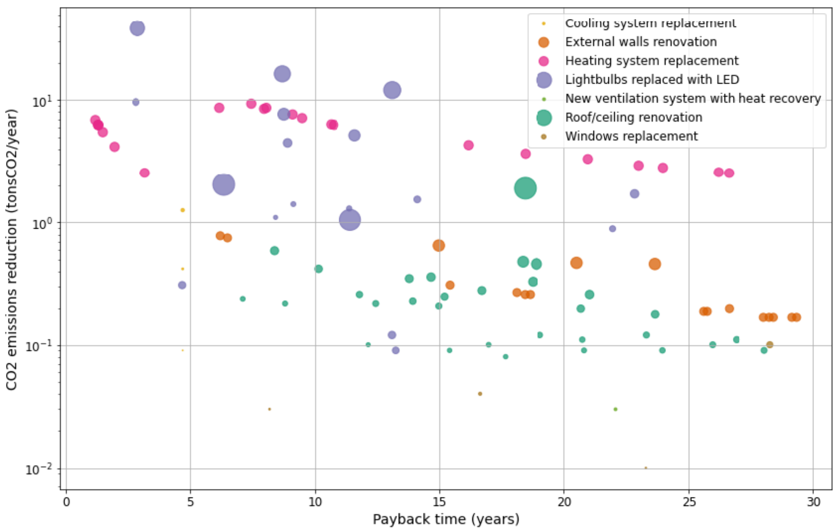

Figure 7. CO_2 emission reduction vs. the payback time of the proposed energy efficiency measures.

5.2. Environmental Evaluation

Relatively isolated communities such as islands [107] and mountain huts [108] are experiencing difficulties in terms of the traditional energy supply and energy security, where renewable energy technologies can make significant contributions [109]. However, due to the limited total resources, the application of 100% sustainable energy systems presents a significant challenge in energy planning for self-sufficiency and sustainability [110]. Dorotic et al. [111] developed a model for the utilization of intermittent renewable energy sources in combination with the vehicle-to-grid concept. The EnergyPLAN tool was applied to model the integration of the electricity power, heating, cooling, and transport sectors. The results showed that the combined capacities with 40 MW wind and 6 MW solar had the lowest cost while the configuration with 22 MW wind in combination with 30 MW solar capacities provided the lowest electricity import and export.

For the case of mountain huts, users, as the are stand-alone micro-grid systems, are not connected to a power grid [112]. Mori et al. [21] presented an integration and optimization process for renewable energy sources in a mountain hut's electricity generation system combined with a lifecycle assessment. Therefore, it impacts on the environment by generating electricity in the installed generators supplied by fossil fuels. The use of renewable energy sources presents a challenge regarding balancing electricity generation and consumption and reducing the environmental impacts. For this aim, a computational model was developed, validated with experimental data, and integrated into a TRNSYS model. This model was applied to a suitable case study, the Refugio de Lizara MH, in a natural park of the Spanish Pyrenees. It has a capacity of 78 people and free access to electricity, hot water, and other services. The electricity for these users is generated by two 22.4 and 12.8 kWe diesel generators (gen-sets) that are used daily during peak demand (breakfast, lunch, and dinner) and a PV system with a nominal power of 3.7 kWp. The energy system was recently modified and upgraded to make it more sustainable and environmentally sound. The installation of additional PVs, a control system, and waste heat recuperation was carried out as part of the LIFE SustainHuts project. In this work, to identify the best arrangement that matches the dynamic loads and meets the electric energy demand, several different electricity generation systems were modeled:

(i) MEAS (the only configuration with real experimentally obtained data with the SOPE): system configuration after the upgrade, PV 3.7 kWp, batteries 38.4 kWh, gen-sets 12.8 + 22.4 kW, and measurement results of actual 1-year operation of the hut.

(ii) SOPE (the state of play at the end): system configuration after the upgrade, same as the measured, used for validation.

(iii) The custom computational model.

(iv) SOPE+: system configuration after the upgrade, same as the SOPE and measured but with a modified battery charging strategy to increase the use of renewable energy.

(v) SOPB (the state of play at the beginning): system configuration before the upgrade for comparison with the current state, PV 0.5 kWp, batteries 38.4 kWh, gen-sets 12.8 + 22.4 kW.

(vi) OPEx2: hypothetical configuration with double PV and battery capacity compared to the SOPE; an improved battery charging strategy was employed as in the SOPE+.

(vii) RES: hypothetical configuration with sufficient PV and battery capacity for fully renewable operation; an improved battery charging strategy was employed as in the SOPE+.

The main results of the different configurations can be summarized in Table 3. The results show that the recent upgrade of the energy system improved the renewables penetration from 8.7% to almost 44.9%. In addition, the optimization of the charging strategy, which was one of the main goals of this paper, improved the renewables penetration to 63.4%, which was a large improvement that required a small investment. Higher renewables penetration results in lower environmental impacts. The global warming potential was decreased by 39% in the case of the system upgrade, including the improved charging strategy (SOPE+), compared to the state of play at the beginning (SOPB). The carbon footprint evaluated by the lifecycle assessment method could be reduced by 34% in the case of the implemented system upgrade, and by up to 47% in the case of 100% renewable electricity generation. An investment cost analysis showed that improving the battery charging strategy has a minor effect on the payback time, but it can significantly reduce the environmental impacts.

Table 3. Results of different configurations.

Description	Unit	SOPB	MEAS	SOPE	SOPE+	SOPE × 2	RES
Total consumption	kWh	8105	7842	8105	8105	8105	8105
Generator output	kWh	8284	4913	5064	3348	638	0
Total fuel consumption, Single phase	L	3408	2021	2083	1378	262	0
Nominal photovoltaic power	kW	0.5	3.7	3.7	3.7	7.4	11.1
Available solar energy	kWh	791	-	5852	5852	11,704	17,556

Battery capacity	kWh	38.4	38.4	38.4	38.4	76.8	192
Excess energy	kWh	0	-	1734	59	2996	7941
Renewable penetration	%	8.7	-	44.9	63.4	93.2	100

Energy retrofit of the facade of condominium buildings always encounters challenges due to the high energy consumption, high cost, high CO_2 emissions, and long payback period [113]. The application of insulation materials is the most common method due to the above constraints, especially for historic buildings [114]. Spanodimitriou et al. [22] proposed refurbishment action involving the implementation of a PVC-coated polyester fabric as an external layer on the main facades of a building. These evaluations were performed by a suitable dynamic model in the TRNSYS environment applied to several Iranian cities, including Tabriz, Teheran, Yazd, and Bandar Abbas, with different climates (cold, temperate, hot-dry, and hot-wet). Different building orientations, aligned either north-south or east-west, were investigated.

In order to promote the application of high-energy-efficiency measures, a total of three incentive policies were suggested to evaluate the performance of existing buildings. A typical seven-story office building from IEA Annex 27 activity was investigated in the present study with a geometrical model with a 661 m^2 floor area and 4.13 m height. Figure 8 illustrates the whole picture of the building from the north-south and east-west orientations. The thermal transmittances of the building are 1.80, 1.20, 1.80, and 6.0 W/m^{2}K for the vertical walls, roof, floor, and windows, respectively. An insulation layer of expanded polystyrene with a conductivity of 0.041 W/mK was adopted to reach the basic U-value thresholds based on the National Building Regulations of Iran. The results indicated that the building with the east-west orientation achieved the best states while Yazd demonstrated the maximal PES and ΔCO_2, with 13.6% and equivalent 45.5 Mg CO_2, respectively. On the other hand, in Yazd, buildings with an east-west orientation showed the best result, with a significant reduction in the annual cooling and thermal energy demand of about 37.9 kWh/m^2/year. Moreover, with the application of the newly proposed second-skin retrofit system, a further reduction in the energy demand for both specific space cooling and heating of 32.2 and 12.3 kWh/m^2/year, respectively, could be achieved. With the consideration of the economic analysis, the payback period could be decreased to almost 30 years less than the north-south orientation cases.

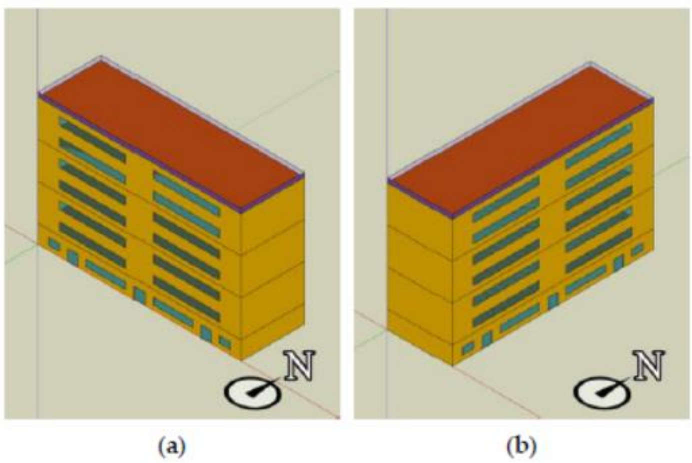

Figure 8. Building with north-south and east-west orientations (axonometric view of the building model in: (**a**) north-south and (**b**) east-west orientations).

6. Conclusions

The literature reviewed in this paper evidently shows that the topics regarding technologies, methods, and economic analysis for sustainable development are essential in order to reach the targets of emission reduction and decarbonization established by many countries. In the present paper, advanced research focused on the application of renewable bioenergy, component enhancement in renewable systems, sustainable development for buildings, and economic analysis and evaluation for sustainability were reviewed. The 13 papers recommended by the SDEWES conference for this Special Issue of *Energies* were also included and introduced in detail. The collected papers provide insight into topics related to recent advances in improving sustainable efficiency, including studies on waste-to-wealth techniques, utilization of hybrid bioenergy systems, heat exchangers and other components for performance enhancement, energy supply and demand analysis, low-temperature DHC systems, techno-economic assessment, and environmental evaluation. On the other hand, the literature presented in the past SDEWES conference series was also presented and introduced in the present review, which can enhance the integrality and consistency of the Special Issue recommended by the SDEWES conference series. In this framework, the reviewed papers are interesting for readers focusing on the fields of sustainable development of energy, transport, water, food, and environment systems; their integration; and their technical, environmental, economic, and social perspectives, etc.

The collected papers provide insight into topics related to recent advances in technologies, methods, and economic analysis for sustainable development of energy, water, and environment systems. In particular, the selected papers present recent advances in four main fields, including the application of renewable bioenergy, component enhancement in renewable systems, sustainable development for buildings and economic analysis, and evaluation for sustainability. The reviewed papers are expected to be interesting for readers who focus on sustainable development of energy, transport, water, food, and environment systems; system integration; and technical, environmental, economic, and social perspectives, etc. However, we should note that some key issues for sustainable development remain to be further addressed, e.g., energy storage systems, low-consumption DHC systems, and techno-economic assessment, which may improve the performance regarding building energy conservation, renewable energy application, DHS development, etc. On the other hand, policy support and market instruments also have crucial roles in the fields of sustainable development. Hence, a comprehensive investigation and evaluation covering technology analysis, economic study, and political exploration should be undertaken, which can be regarded as interdisciplinary research in the coming future.

Future SDEWES conferences will further propagate the sustainable development concept in the energy, water, food, transport, and environment areas. Advanced research from the technical, economic, and social perspectives will be followed by SDEWES people closely. Further information and activities related to the SDEWES conference series can be found on the website of the the International Centre for Sustainable Development of Energy, Water and Environment Systems (SEWES Centre).

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