OVERVIEW

Sustainability of energy, water, and environmental systems: a view of recent advances

Special issue dedicated to 2021 conference on sustainable development of energy, water, and environment systems

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Abstract

This paper presents an overview for the Special Issue (SI) of Clean Technology and Environmental Policy journal (CTEP), and it includes accepted papers from 16th Conferences on Sustainable Development of Energy, Water and Environment Systems (SDEWES) held from October 10–15, 2021, in Dubrovnik, Croatia. Considering CTEPs policy of high-quality research papers, guest editors have invited 35 research articles, presented at the SDEWES 2021 conference. After a vigorous review process, 12 papers have been accepted for publication in this special issue. All 12 accepted papers are briefly presented in this overview together with a wider view that presents research efforts within the SDEWES community published through previous SDEWES special issues.

Keywords Energy transition · Sustainability · Renewable energy sources · Energy efficiency · SDEWES

Introduction

SDEWES conferences always focus on the interdisciplinarity of sustainability issues allowing a wide range of topics. This presents an excellent opportunity for scientists from various research fields to discuss sustainability more holistically. In general, SDEWES conferences cover various topics from economic, engineering, environmental, and social studies, to the studies which assess and measure the sustainability of energy, transport, water, environment, and food production. In this year's special issue, the following topics can be identified.

– Energy transition (circular economy, sustainable electrification, and renewable energy sources
– Sustainability assessments (energy policy, LCA, and technology improvements)

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Energy transition

The energy transition is one of the most discussed and researched topics within SDEWES conferences. It was continually present in the conference series from the very beginning. It gives a wide scope of technologies and policies crucial for transitioning to low-carbon society. Renewable energy sources are the cornerstone of this process. Within this year's SI, the focus was geothermal energy. The Pannonian Basin, partly located in Croatia, is well known for its higher-than-average geothermal gradient with good potential for geothermal energy exploitation. Despite this, the exploitation of geothermal energy proceeded slowly until 2018, when the legal framework was changed. Accordingly, in (Tuschl et al. 2022) an overview of the current state of geothermal energy utilization in Croatia and its prospects is carried out. The interest in developing geothermal projects is seen in 13 exploration and six production licenses issued in the last three years, focusing on deep geothermal potential. The planned use of these granted licenses varies from electricity production to agricultural use. Aside from classic geothermal brine production, there is also a good potential for geothermal brine exploitation from bottom aquifers in

depleted oil and gas fields. Finally, it was concluded that the greatest potential of the Croatian Pannonian Basin lies in high temperature and for exploration and exploitation from deep geothermal sources. This topic has been a focus of several SDEWES SI research papers. In (Macenić et al. 2020), it is elaborated more than 150 deep oil and gas exploration wells scattered in the Croatian part of the Pannonian Basin were elaborated. The study proposed a novel geothermal gradient map and temperature maps for a depth of 1000 and 2000 m. In (Barkaoui et al. 2016), geothermal potential is examined within residential, commercial, and industrial systems based on Pinch analysis. The result of this study gives recommendations for geothermal wells placement as well as for energy planning and regional sustainability. In (Somogyi et al. 2017), an overview of the recent scientific literature concerning geothermal heat pumps is carried out and the existing regulations and technical guidelines in selected European countries are analyzed.

A milestone of the energy transition is the electrification of the transport sector. With the increase in electric vehicle (EV) penetration since EVs are becoming more competitive in price due to the low cost of ownership, which is a consequence of the presence of purchasing incentives and the lower fuel-related and non-fuel-related operating costs characterizing battery EVs compared to other powertrains. Due to that the need for charging infrastructure arises. The most suitable locations for EV chargers are existing fuel stations as the drivers are accustomed to the locations and the incremental cost of providing this service will be lower. In (Ghosh et al. 2022), a novel methodology to assess the techno-economic feasibility of retrofitting an existing fuel station with EV charging infrastructure also known as electric vehicle supply equipment (EVSE) was proposed. To further enhance the value proposition, the potential of integrating a battery energy storage system (BESS) and onsite photovoltaics (PV) with EV charging infrastructure is studied. Results showed that the configurations with 4 EVSE, 1 BESS, and 8 h of operation and the configuration with 4 EVSE, 1 BESS, and 1 PV system for 8 h of operation are economically viable. The above-mentioned configurations are the most economically feasible in terms of the net present value, internal rate of return, and discounted payback period among the other configurations considered in this study. The proposed methodology indicates that though the connection cost is the dominant factor affecting the feasibility, the use of BESS with or without PV can reduce the connection cost by almost 90% depending on the capacity of BESS. Another study on EV charging infrastructure within SDEWES SI is carried out in the study (Foley et al. 2013). In this study, an effect of a high number of electrical vehicles on the operation of the single wholesale electricity market is investigated. Results from this study confirm that off-peak charging is more beneficial than peak charging and that

charging EVs will contribute to the energy supply, a higher share of renewables in the energy supply, and CO$_2$ reduction. In (Škugor and Deur 2015), a dynamic programming (DP)-based optimization method of charging an EV fleet modeled as a single, so-called aggregate battery is proposed. The DP algorithm has an advantage because of minimizing the charging energy cost and satisfying the aggregate battery charge sustaining conditions. The proposed DP optimization method can be used in various energy planning studies, as well as a core of the supervisory/aggregator level of hierarchical EV fleet charging strategies. In (Fan et al. 2022), it is identified that the time series greenhouse gas (GHG) emission pattern of power generation and the potential emission reduction by altering the charging behavior is assessed. This study aims to facilitate EV development in reaching full potential contributions to sustainability.

The transition of the building sector toward low-carbon solutions requires a novel technology mix that will allow the synergy between them. The increased use of heat pumps to utilize low-temperature heat (30–50 °C) will undoubtedly be a part of future emission reduction measures within the heating sector. Identifying these heat sources and assessing their heat potential is essential for their utilization. This research (Sundell and Rämä 2022) aims to present a replicable estimation methodology that can be applied to any urban area. Methods for estimating the potential of the heat sources were developed based on the findings of the literature review and the expected availability of data. The methods presented give an overview of how heat potential could be estimated. It can be used as a base for developing more refined methods and for detailed techno-economic assessment for utilizing available excess and natural heat sources. Papers in a similar area of research have already been published in SDEWES SI. In (Østergaard and Andersen 2016), the role of booster heat pumps (BHP) and central heat pumps in the district heating sector is examined and concluded that BHP is important for the integration of low-temperature heat and enables the reduction of the temperature regime in the network. Another SDEWES SI study is (Nielsen and Möller 2012) where the production of waste heat from net-zero energy buildings (NZEB) was investigated. The results from their study showed that excess heat from NZEB buildings is suitable for integration into district heating systems. An important study (Doračić et al. 2018) evaluated excess heat utilization in district heating systems by implementing levelized cost of excess heat. This study has demonstrated the economic and environmental benefits of switching from individual heating solutions to a district heating network with a high share of excess heat.

Circular economy and waste management present one of the most challenging parts of the energy transition. Landfilling is still the most common way of municipal waste treatment in around half of the EU countries. Such things were

asserted in a recent study (Putna et al. 2022) where it is shown that diverting some of the waste-to-energy recoveries makes it possible to reduce emissions of various pollutants, especially when the waste replaces lower-quality fossil fuels in heating plants. The study proposes the methodology to determine the influence of a waste-to-energy plant with a processing capacity in the range of 10 to 150 kt/y integrated into an existing district heating system on the air pollution load in the surrounding area. The parameters of the existing heating plant, such as the fuels used and the boiler output range, are considered. The results show that by using the methodology, it is possible to directly quantify the impact of waste-to-energy plant integration on the health burden of the surrounding population in comparison with the reference state. The methodology is tested via a case study in which it turned out that the immission load can be significantly reduced up to 83% compared to the original state in the calculation scenario. Other papers on waste-to-energy are also presented in SDEWES SI during the last few years. The (Zsigraiová et al. 2009) study proposes a model with integrated waste transportation optimization and incineration with energy recovery combining the production of heat and power. The model also performs environmental and economic assessment, and it shows that the proposed CHP solution decreases GHG emissions and that the revue from energy sales can balance the incineration cost. In (Lam et al. 2013), a green strategy for the systematic design of a waste-to-energy supply chain is examined. The proposed strategy includes efficient resources management and reductions of the carbon footprint of a waste-to-energy supply chain and results operation, logistics management, and optimal technology to convert waste into value-added products are determined. A recent study (Putna et al. 2020) presented a comprehensive mathematical optimization tool working on a daily time interval that can evaluate the impact of changing current technology or waste-to-energy plant construction on global warming potential. The method evaluated the relationship between GHG saving and the economic benefits of the integration of a waste-to-energy plant. Biomass waste contains an abundant source of energy that can be transformed into high-calorific fuel during intermediate pyrolysis, consequently reducing the use of fossil fuel resources. In the (Jerzak et al. 2022) study, medium-density fiberboard (MDF), brewery spent grains (BSG), and post-extraction soybean meal (SM) were used for pyrolysis. Chars obtained from these feedstocks were characterized by different internal microstructures. The surface of MDF char has exhibited pores with a regular pattern of small perpendicular blocks. On the other hand, irregular open spaces were detected in BSG and SM chars. The results of this research on the microstructure proved that biomass wastes are perspective feedstocks to obtain high-value bioenergy products. A recently accepted SI SDEWES study is (Zhang et al. 2021) where

the research on the Bio-CPD model to predict the pyrolysis products of softwood and hardwood was done. Based on the results, the study proposed two empirical-simple forms of pyrolysis models that were further optimized. An interesting and novel publication (Ahmad et al. 2021) for the first time evaluated the feasibility of maple leaf waste (MLW) to produce biofuel–bioenergy and chemicals. The study showed that MLW has an average value of activation energies (75–91 kJ mol^{-1}), high heating values (16.32 MJ kg^{-1}), Gibb's free energies (261–269 kJ mol^{-1}), and change in enthalpy (68–85 kJ mol^{-1}). It is demonstrated that MLW has significant potential for bioenergy production and suitability of co-pyrolysis with other waste and biomass feedstock. In (Sobek and Werle 2021), fixed-bed solar pyrolysis of three waste biomass types: waste wood, waste straw, and sewage sludge with emphasis on heating behavior, product yields, and quality is examined. Correlation between model-free kinetic predictions and gaseous species evolution was found and the value of apparent isoconversional activation energy profiles in describing actual solar pyrolysis gas compound formation at the laboratory scale was proved.

Sustainability assessments

Various indicators and methods are used in sustainability assessments, energy policy improvements, and clean technology alternatives. Within this overview, several authors are trying to tackle these issues. The oil and gas industry, as a key contributor to GHG emissions, must transition to more sustainable energy solutions and play its part in reducing GHG emissions. Oil and gas companies have identified and started implementing technical solutions to achieve a net-zero carbon future. Therefore, in (Wong et al. 2022) the social perception of a net-zero carbon future is examined. The study reviews Malaysia's low-carbon policy plans, and its current carbon dioxide accounting balance, and identifies potential technologies for decarbonization. The results indicated that the national oil and gas company has both the capabilities and the financial resources to significantly contribute toward Malaysia's transition to a carbon–neutral nation. This study also portrays the confidence that the portfolio of solutions should be executed through a coordinated effort to maximize the outcome and minimize the financial impact in terms of economical sustainability. Policy and plans toward energy transition and the green and sustainable economy was topic of many other SDEWES SI papers. In SI SDEWES published research (Yatim et al. 2016), the historical evolution of Malaysian energy policies and initiatives designed to secure diverse energy sources and avoid over-reliance on fossil fuels is reviewed. This research also discusses challenges and concerns over the future of sustainable energy in Malaysia. In (Pleßmann and Blechinger 2017), the multi-regional power system model which can

analyze a least-cost decarbonization strategy for the European continent with a focus on Southeast Europe is developed. Results underline the possibility and the enormous efforts required to achieve decarbonization. In (Hvelplund and Djørup 2019), citizen and consumer ownership models were examined. Also, the influence on consumer prices and their capability to handle the multitude of coordination tasks in a transition from sector-based to integrated smart energy systems were studied. Results showed positive potentials both in terms of maintaining a low energy price base that can 'pay for' the extra costs of a first mover 'premature' introduction of costly new energy technologies and securing low coordination transaction costs linked to the multitude of an hour to hour and investment coordination tasks in a transition from sector-based to integrated smart energy systems.

The EU legislation put the focus on the material recovery of waste while energy recovery is not elaborate enough and all thermochemical conversion technologies are classified in the same category regardless of the final products, which can hamper overall sustainability. Therefore, (Tomić et al. 2022) authors analyzed technologies for the recovery of plastic waste to review the existing EU legislation and technology classifications. As alternative thermochemical recovery technologies are not widely used, their inventories were modeled based on an extensive literature review. Results show that pyrolysis of plastic waste has 46, 90, and 55%, while gasification up to 24, 8, and 91%, lower global warming, abiotic depletion, and cumulative energy demand-related impacts, respectively, compared to incineration with CHP generation. Results of this analysis provide levelized results for environmental and resource sustainability based on which current legislative views on individual thermochemical recovery technologies may be re-examined. Various thermochemical recovery setups are analyzed through SDEWES SI papers. Another important study on a similar topic is (Kremer et al. 2021) where it is a study on the assessment of the thermogravimetric behavior and kinetic parameters of the real-world plastic waste mixture with added nickel- and iron-based catalysts on gamma-aluminum oxide as support performed. The kinetic analysis results showed a complex decomposition mechanism of the real-world plastic waste mixture. A recent publication (Larrain et al. 2020) compared the economic performance of the pyrolysis of mixed polyolefin waste in a closed-loop and open-loop scheme, including a probabilistic approach to the most important variable. Results from the study showed that open-loop pyrolysis outperforms closed-loop pyrolysis due to the high prices of wax. In (Feil et al. 2017), a techno-economical evaluation of the processing results of waste sorting plants which would provide a realistic assessment of the recovery yields of valuable materials and the qualities of the obtained products is carried out. By model results, calculations, and/or adjustment of assumptions, information concerning weak points in

the process can be identified, which can be used for further plant optimization.

Sustainability assessments are cross-sectoral and applicable. In one of the SI papers, drivetrains in the passenger car sector were the focus. To strengthen the economic pillar in sustainability assessment, the indicator 'domestic value added' ('DVA') is introduced. In (Harzendorf et al. 2022), this is done by classifying a technology's value added to the developed categories: domestic, potential domestic, and non-domestic. Within this paper, two methods for assessing this indicator are introduced and both methods are tested in a case study comparing two alternative drivetrain technologies for the car sector (battery and fuel cell EV) to the conventionally used internal combustion engine (ICE). The first method is life cycle cost-based, whereas the second is based on input–output analysis. From the 'DVA' perspective, the battery EV is more advantageous than the conventional ICE over the lifecycle. Fuel cell EVs have the highest potential to increase 'DVA' share in the future. This paper broadens the economic pillar in sustainability assessment by introducing a new indicator 'DVA' and giving practical information on how to prospectively assess it for existing and less developed technologies. Another SDEWES contribution to the subject can be seen through the following studies. In (Ajanovic and Haas 2019), the overall environmental impact of EVs including emissions from electricity generation, vehicle production and disposal, and vehicle use is investigated. The major conclusion is that the environmental benignity of EVs is very sensitive to electricity mix, the number of km driven per year, and embedded emissions in car production, as well as battery recycling. In this paper, it is shown that the highest sensitivity is concerning the electricity mix. To make EVs more environmentally friendly, it is important to increase the share of renewable energy sources in electricity generation which was investigated in an interesting study (de Souza et al. 2018). The study evaluated and compared the environmental impacts of vehicles in the Brazilian context. A life cycle assessment is carried out to assess the well-to-wheels for different scenarios of fuel consumption and powertrains configurations for a vehicle. The study concluded that the Brazilian government should increase its investment and develop the use of EVs, since the country's electric mix is renewable, as well as further encourage the use of ethanol since it generates less environmental impact than gasoline. Another study on a similar topic is (Ajanovic and Haas 2017) where possible GHG emission reductions due to different policy measures implemented in passenger car transport in the EU-15 were discussed. The major instruments analyzed are fuel and registration taxes, that support measures for biofuels as well as standards for specific CO_2 emissions from new passenger cars. The result showed that GHG emissions could be reduced at least by 33% in a

selected policy scenario compared to a business-as-usual scenario up to 2030 by combining different policy measures.

Reducing GHG emissions in the transport sector is also one of the biggest challenges in the German energy transition. In this paper (Haase et al. 2022), a comprehensive sustainability assessment for passenger vehicles is conducted for 2020 and 2050. The discussed options are an internal combustion engine vehicle (ICEV) fueled with synthetic biofuel and fossil gasoline, a battery electric vehicle (BEV) with electricity from wind power and electricity mix, and a fuel cell electric vehicle (FCEV) with hydrogen (H_2) from wind power. For integrated consideration of the different indicators, the MCDA-method Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is chosen. The results showed that the BEV with wind power is the most sustainable option in 2020 as well as in 2050. While in 2020, the second rank is taken by the ICEV with synthetic biofuel from straw and the last rank by the FCEV, in 2050 the FCEV is the runner-up. With the help of the proposed MCDA, transparent and structured guidance for decision-makers in terms of sustainability assessment of motorized transport options is provided. The sustainability of alternative technologies and fuels in transport has already been the subject of several articles in SDEWES SI. In (Bellocchi et al. 2020), the electrification of the transport and heating sectors with the support of renewable energy sources is analyzed. A conducted study found that GHG emissions can be reduced by 25–30% in the case of electrification of the sector. As an important part of the electrification of the transport sector, the study proposes the implementation of smart chargers that provide high flexibility in the electroenergetic system. Another important study is (Ajanovic and Haas 2021) where the authors investigated the possibility of H_2 and fuel cell vehicles in the transport sector. In the study were recognized the major challenges for H_2 and fuel cell vehicles higher penetration due to the high costs of technology and infrastructure, as well as the lack of a stable policy framework. The study concluded that the best prospect for H_2 and fuel cells is in large-capacity vehicles. A recent study (Omahne et al. 2021) carried out an overview of transport-related life cycle assessment (LCA) studies, as they are vital for the decision-making processes. Results from this study represent a comprehensive overview of the LCA research and suggest improvements in the methodological approach to LCA analysis.

The COVID-19 crisis has brought unprecedented challenges to many sectors, including the construction and demolition industry (CandD). This industry has been affected by the pandemic in many ways. Important research on this topic is (Shooshtarian et al. 2022) where COVID-19 impacts the Australian CandD, waste recovery, and construction industry as the major waste consumer and generator analyzed. The research findings established that there is a critical need for leveraging digital technologies, developing business contingency plans, creating coalitions between government and industry, and diversifying supply chains to reduce supply chain risks. This study also uncovered a range of targeted responses and recommendations to manage pandemic-induced disruptions and improve the circular economy in the industry. In SDEWES SI, construction industry is a frequently treated topic, especially waste management and resource recovery from the construction industry. In the first SI SDEWES papers (Mulavdic 2005), a model for optimization of construction technology based on aspects of sustainable development as a set of multi-criteria: energy consumption, renewable resources use, and air pollution is proposed. A contribution to this is also given in the study (Johnsson et al. 2020) which establishes a robust framework for the assessment of sustainable development goals (SDG) in business with an emphasis on the construction industry. The study provides a critical analysis of a selection of relatively widely used SDG impact assessment tools, combined with a case study from the construction industry to explore how a meaningful SDG assessment can be framed with linkages between climate changes and other related SDGs. Another study on recycling construction and demolition waste is (Oliveira Neto and Correia 2019). This study has shown that there are economic and environmental advantages associated with the use of reverse logistics for solid waste treatment and recycling in the construction industry.

Various technology improvements and implementation are the focus of SDEWES SI sessions. In this year's conference, the special focus was on wastewater treatment. Micropollutants are persistent and hazardous materials in relatively low concentrations (ng L − 1–µg L − 1), including substances such as pharmaceuticals, personal care products, and industrial chemicals. The advancement of analytical chemistry has allowed for the detection of micropollutants; however, an efficient and economical treatment solution is yet to be installed. Fungal laccase has been a successful biocatalyst of these compounds. However, large-scale application of free enzyme is currently not feasible for removing water-borne micropollutants, partly due to relatively rapid loss in enzyme stability. In (Meiczinger et al. 2022), three types of cyclodextrin, α, β, and γCD, to immobilize the laccase under various conditions to improve the stability of the enzyme are examined. Results showed an optimum using α-cyclodextrin immobilization. At that level, α-cyclodextrin increased the half-life of laccase and slightly improved its activity in all tested pH by physically bonding to laccase. In (Grobelak et al. 2018), optimization and testing of plant growth-promoting rhizobacteria (PGPR) soil bio-preparation and soil amendments as the alternative to or to help offset the use of mineral soil fertilizers are carried out. The conducted study confirmed that the PGPR bacteria used in the

experiment have the potential to promote plant growth and increase organic nitrogen in the bioavailable P pool in soil. (Tan et al. 2015) reported the use of an osmotic membrane bioreactor for municipal wastewater treatment. In (Nowak et al. 2015), a discussion on the major ways in which the energy balance of municipal wastewater treatment systems can be optimized is carried out. Studies have shown that wastewater treatment plants can reach up to 180% energy generation compared to the energy needs while switching from wastewater to cooling water regeneration as the heat source of heat pumps for district heating can offer electricity savings of up to 45%. However, negative effects on the environment like insufficient wastewater treatment or the release of methane gas into the atmosphere must be avoided.

Agricultural and municipal wastewater effluents contain valuable nutrients which can be recovered and recycled for agricultural application to close the gap between urban food consumers and rural agricultural producers. A recently published study (Ghimire et al. 2022) presented a detailed evaluation of novel and sustainable materials for the construction of microbial electrochemical systems. Terracotta (an earthly material) and agricultural waste-derived biochar materials were used to construct a microbial electrochemical system. Municipal and agricultural (dairy production) wastewaters were evaluated for the potential resource recovery in the novel, sustainable microbial electrochemical systems. The results confirmed the beneficial use of sustainable materials for resource recovery applications in agricultural systems. Energy and nutrient recovery from wastewater treatment plants is always an actual topic within SDEWES conferences and different views on this topic were proposed. A year earlier it published an interesting study (Piwowar et al. 2021) that characterizes the supervision and institutional support in terms of the reduction of water pollution from agricultural sources in Poland. In (Pena et al. 2017), a study on a bench-scale depuration assay of swine wastewater using Lemna minor is carried out. The study showed a clear improvement in specific methane production rate when compared to mono-substrate anaerobic digestion. A hybrid system for sewage sludge drying is examined in the study (di Fraia et al. 2018). The developed layout is based on the integration of two renewable energy sources, biogas from the anaerobic digestion of sludge and solar energy to increase the sustainability and energy self-sufficiency of the plant. A hybrid system will lead to a primary energy saving of about 14.6% concerning the existing plant where the sludge is not digested and neither thermally dried. The economic analysis shows that the simple payback period of the system is less than 3.4 years.

Conclusion

As already mentioned, SDEWES conferences are a perfect place to present research topics in a holistic surrounding, allowing scientists to have a wider view of sustainability issues. Looking at this overview, an interdisciplinary approach can be seen through various topics; from clean technologies and procedures connected to water and air treatment to various renewable energy technologies. To work on various mitigation policies, different research fields need to work together. Therefore, this overview is used to show the wide range of research papers that present a systematic approach to SDEWES special issues present, in gathering knowledge in the field of sustainable energy, water, and environment systems. All those research topics are at the center of CTEPs interest, making SDEWES conferences fit perfectly.

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Data Availability Enquiries about data availability should be directed to the authors.

Declarations

Competing interests The authors declare no competing interests.

Conflict of Interests The authors have not disclosed any competing interests.

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