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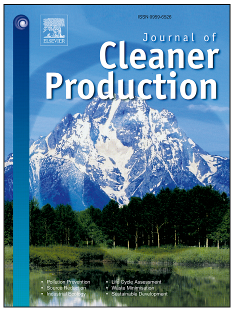

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System Integration is a Necessity for Sustainable Development

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Highlights

- Three systems are of strategic importance to sustainable development.
- These three systems are energy, water, and environment.
- Integration of these systems is a necessity for a sustainable development.

Abstract

Following the 2015 Paris Agreement, the main challenge for world economies nowadays is to commit themselves to long-term reforms aimed at increasing and promoting sustainable, inclusive and balanced development. An adequate response to this challenge will certainly require using the best available scientific knowledge and constant re-evaluation of the development process in light of the scientific findings. To ensure that the sciences are responsive to the emerging needs and to address sustainable development issues. This Virtual Special Issue of the Journal of Cleaner Production is dedicated to both Sustainable Development of Energy, Water and Environment Systems 2016 Conferences – 2nd South East European Sustainable Development of Energy, Water and Environment Systems Conference and 11th Sustainable Development of Energy, Water and Environment Systems Conference. The Virtual Special Issue is focused on four main fields: Energy issues, Water issues, Environmental engineering and management, and

Sustainable engineering solutions and large-scale sustainability approaches. The division of selected papers follows the previous Journal of Cleaner Production Special Sections and Volumes dedicated to the Sustainable Development of Energy, Water and Environment Systems Conference series.

Keywords: Energy; Water; Wastewater; Waste management; Environmental engineering; Sustainable engineering solution

1. Introduction

Sustainable development is a highly interdisciplinary concept that involves interaction of various systems. Integrating various systems, as energy, water, and environment, by using waste from one, as resource in other, and in exact moment when it is beneficial to all, is becoming a necessity for a sustainable, inclusive and balanced development (Mikulčić et al., 2017). To address this issue, at the beginning of this century the Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conference series was established.

In 2016, two SDEWES conferences were held. First time in July, it was the 2nd South East European SDEWES Conference (SDEWES SEE 2016) in Piran, Slovenia, and the second time in September, it was the 10th SDEWES Conference (SDEWES 2016) held in Lisbon, Portugal. Both conferences, SDEWES SEE 2016 with 195 participants and SDEWES 2016 with 324 participants, brought together researchers from around the world, to meet, share, and discuss their ideas and findings, in order to ensure that the sciences are responsive to emerging international, European, regional and national challenges.

The papers in this Virtual Special Issue (VSI) are based on articles presented at both SDEWES Conferences in 2016. The two conferences covered various research topics, from the technical, economic, environmental and social studies, to the studies which investigated the sustainability of energy, transport, water, environment and food production systems and their interconnection and integration. From 475 accepted manuscripts, that were presented at both SDEWES Conferences 24 were selected for this Journal of Cleaner Production (JCLEPRO) VSI. As a results of a successful cooperation between the JCLEPRO and the SDEWES Conference series, this VSI is a sequel of previous SDEWES Conferences reports and reviews, and follows their format. The papers within the VSI SDEWES 2016 are divided into four research fields that have been established by the previous JCLEPRO Special Issues and Special Volumes dedicated to the SDEWES Conferences. These research fields are: Energy issues (8 papers); Water issues (4 papers); Environmental engineering and management (6 papers); Sustainable engineering solutions and large-scale sustainability approaches (4 papers). Hence, the previously generated SDEWES knowledge base in these four main research areas is extended by this JCLEPRO VSI.

2. Background

The content of this section is based on the papers published under this and other journal's Special Sections or Volumes dedicated to SDEWES conference series. The papers reviewed in this section are classified into four research fields (Energy issues; Water issues; Environmental engineering and management; Sustainable engineering solutions and large-scale sustainability approaches) as in the main part of this manuscript, that is Section 3.

Secure and accessible supply of energy has become an important goal of all modern societies. The switch from fossil fuel based to renewable energy based power generation, and the complexity of the interlinking of fossil and renewable energy resources, have been extensively investigated due to depleted fossil fuel reserves, and increased environmental concerns (Vidal-Amaro and Sheinbaum-Pardo, 2018). In that vein, ways to improve and rationalize the use of fossil fuels in existing furnaces were experimentally investigated by Kazagić et al. (2014).

Increased need for clean and environmentally friendly production of goods in industrialized countries, induces increased demand for energy of “green and clean” origin, produced by hydro, wind, geothermal, solar, and biomass power plants (Perković et al., 2018). Accordingly, energy production from renewable energy sources has been reported in numerous studies. Papers reported the energy production from power plants using geothermal energy (Martinez-Gomez et al., 2017), gas turbines using alternative fuels (Seljak et al., 2016), hydro power plants (Sahin et al., 2017), biomass power plants (Rajh et al., 2016), photovoltaics in Hong Kong (Zhang et al., 2017) and Portugal (Casaleiro et al., 2018), wind power plants in Brazil (Schmidt et al., 2016) and Russia (Ermolenko et al., 2017), and hydrogen for transport purposes (Firak and Đukić, 2016).

Rational energy use and emission reduction in energy-intensive industries has been the topic of many research papers. Energy improvements in steel production have been the focus of study of the papers by Gajic et al. (2017) who analyzed the production of stainless steel, and Dal Magro et al. (2017) who investigated the coupling of waste heat with superheated steam generation in the steel industry. Chinese et al. (2017) assessed the nexus of water, energy and greenhouse gas in alternative heat recovery options in the European steelmaking. The study by Araújo et al. (2017) evaluated CO_2 separation alternatives applicable to enhanced oil recovery as the destination of carbon dioxide. The fuel consumption, heat integration, lowering of CO_2 emissions, and improvements in production of cement were investigated by Boldyryev et al (2016).

Biomass as a renewable energy source that could easily replace fossil fuels has been studied extensively in Austria by Maier et al. (2017), in Japan by Ooba et al. (2016), and in Malaysia by Shen How et al. (2016). Bioethanol production from de-oiled microalgal biomass was investigated by Muei Chng et al. (2016). Marques et al. (2018) analyzed different options for pretreating microalgal biomass to enhance biogas production. Cheah et al. (2017) made a techno-economic analysis of diesel fuel production by hydro-processing of rubber seed oil. Refining of crude rubber seed oil as a feedstock for biofuel production was studied by Singh et al. (2017). Biomass gasification in a co-current fixed bed gasifier was discussed by Mikulandrić et al. (2016). As a quarter of the total primary energy demand in the European Union is met by natural gas, Miedema et al. (2016) investigated a more sustainable energy supply system using synthetic natural gas produced through biomass gasification.

Transport sector as a significant emitter of greenhouse gases has been extensively studied. As internal combustion engines are still the predominant technology used in transport vehicles, their efficiency improvements, and gas emissions are still considerably investigated. Petranović et al. (2017) showed that the engines fuelled with biodiesel blends release lower nitrogen oxide emissions than those fuelled with regular diesel.

However, current trends in the transport sector development indicate increasing role of lithium-ion batteries, which will lead to a significant greenhouse gas reduction. Teixeira and Sodré (2016) reported that electric vehicles electric energy consumption is about four times lower than conventional vehicles fuel energy consumption , and carbon dioxide emissions are 10-times lower.

Socio-economic and socio-technical studies related to sustainable energy systems, energy savings, and pollutant reduction have highlighted the challenges that are put on the society, in order to adapt to the evident climate changes (Hinker et al., 2017). As stated by Klemeš et al. (2013), the focus of modern engineering education in the field of energy systems is to educate new energy engineers to manage and solve pertinent problems in a sustainable way. Different energy technologies, processes and management options have different impact on the human welfare (Novak Pintarič et al., 2015). Thus, the socio-economic aspects of the switch from a fossil-fuel based to renewable-energy based energy system need to be considered carefully (Kozioł and Mendecka, 2015).

Amongst the papers dealing with *Water issues*, the access to fresh water and its management in arid and semi-arid areas, where rain and dew water can have a significant impact as new sources of water, were investigated by Sharan et al. (2017). Urban factors affecting water consumption in Italy was studied by Romano et al. (2016). Using a structured questionnaire, Liefferink et al. (2017) investigated the current water use of municipal and river water, water availability and quality, and future water use needs in a South African community. Since some regions suffer from depleted groundwater resources, utilization of alternative water sources is prudently studied. Czarny et al. (2017) showed that in rural areas, where access to drinking water is scarce, rainwater after appropriate treatment process, can be used as potable water. For remote communities on islands and in isolated mainland, Beal et al. (2016) investigated the retrofitting of households with water-efficient devices and appliances; where water is a scarce resource, it must be carefully preserved and managed, to make it available to all.

Interactions between energy supply and water use attracted the attention of many researchers. Kumar (2017) studied the consequences of the enforcement of building regulations on energy and water use in Indian hill towns. The study showed that regulations, if not efficiently enforced and followed, lead to excessive use of already scarce water and energy resources in India. Kollmann et al. (2017) discussed the practical aspects of integrating a wastewater treatment plant into local energy supply concepts, as they have high potentials for heat generation. The integration of renewable energy resources and reverse osmosis desalination in an arid country, for fresh water supply was investigated by Novosel et al. (2015). The desalination process was also studied by Suárez and Urtubia (2016) who investigated the performance of a direct contact membrane distillation system driven by salt-gradient solar ponds, and showed that the coupled system can be used to meet the future needs of energy and water use in a sustainable way.

The wastewater treatment measures and efficient water use in industry have been highlighted in many studies (Fijalkowski et al., 2017). Focusing on textile mills, Ozturk et al. (2016) studied the minimization of water use, while Yukseler et al. (2017) investigated the best available techniques for the treatment of wastewater. Colla et al. (2016) presented the possibilities for water reduction in steelmaking plants. Combining heat exchanger network and water network (Ibrić et al., 2016), and integrating water networks between different plants (Ibrić et al., 2017), makes it possible to attain savings in water consumption.

Water quality control, prevention of possible toxic substances and removal of contaminants from aqueous solutions have been investigated extensively. Haslik et al. (2017) measured and investigated the presence of toxic substances in wastewater from nuclear power plants. Riverbank filtration in order to purify the water for communities in India, was studied by Kumar et al. (2017). Adsorptive removal of 2,4-dichlorophenoxyacetic acid from aqueous solution using bagasse fly ash as adsorbent was presented by Deokar et al. (2016).

Among the papers dealing with Environmental engineering and management, several studies analyzed the influence of different pollutants on human health, waste management, waste minimization, recycling, formation and reduction or air pollutants, environmental impact assessment studies, and many other topics. Atmospheric emissions from industry in the Moravian-Silesian Region in Czechia, have been a topic of the studies by Sýkorová et al. (2017) who investigated the total air pollution, and by Štrbova et al. (2017) who analyzed the influence of fugitive sources and meteorological parameters on the vertical distribution of particulate matter. Focusing on the city of Ostrava in the same region, Kubcel et al. (2017) studied the temporal and seasonal variations in black carbon emissions. Bjørnåvold and Van Passela (2017) discussed sustainable solution for automotive cooling systems. The influence of different fuels on pollutant formation and the reduction potential of greenhouse emissions from cement production was investigated by Mikulčić et al. (2016). The reduction of NO emission by the selective non-catalytic reduction deNOx process was demonstrated by Baleta et al. (2016). Chandrashekhar and Pandey (2017) investigated the use of a biochemical process for the reduction of nitric oxide (NO) from stationary gaseous emissions.

The influence of iron and steelmaking industry on soil quality was analyzed by Strezov and Chaudhary (2017). Gheju and Balcu (2017) investigated the remediation of chromium pollution by application of phosphate and sulfate. In the subsequent study, Gheju et al. (2017) analyzed the hexavalent chromium removal with metallic iron, Grobelak et al. (2017) performed field experiments in the contaminated area near a zinc smelter where poor soil fertility and high concentrations of cadmium, zinc and lead had been detected. Ferrucci et al. (2017) presented an analytical tool that can be used to better estimate the average soil contamination.

Hartmann et al., (2015) studied the handling of hazardous waste from municipal solid waste incinerator plants, and showed that carefully and responsibly handling of the incinerator fly ash is needed.. Raclavska et al. (2017) analyzed different fly ash samples from waste incineration plants, showing that proper disposal of fly ash as hazardous waste can heavily depend on its composition. Application of waste ceramic dust as a replacement of cement in lime-cement plasters was investigated by Kočí et al. (2016) who concluded that it is an energy-efficient and environmental-friendly solution for handling of waste ceramic dust.

Solid waste management systems and the recycling of solid waste materials can be named as topics that had been studied most extensively. Natural disasters and handling of the resultant significant amounts of waste generated were studied by Tabata et al. (2016). Municipal solid waste composition, as well as collection and handling, in the Brazilian region of São Paulo State, were studied by Deus et al. (2017) and by Oliveira et al. (2017); the latter study focused on landfill options in the city of Bauru. Using the energy consumption and return approach, Tomić and Schneider (2017) investigated the municipal solid waste management system in Croatia. The social and economic aspects of waste treatment techniques, as well as making decisions on their application and planning were discussed by Milutinović et al. (2016). Recycling and utilization of the waste paper in the manufacture of paper were reported by Seo et al. (2017).

In the field of *Sustainable engineering solutions and large-scale sustainability approaches*, several new approaches and methodologies have been demonstrated. The life cycle assessment (LCA) method has emerged as a valuable decision-support tool for assessing the cradle-to-grave impacts of a product or process on the environment. It has been extensively used in various applications and sectors such as assessing different carbon capture and storage technologies (Troy et al., 2016), and environmental impacts of a standard 20-foot cargo container (Obrecht and Knez, 2017), as well as in evaluatimg domestic solar hot water systems (Zambrana-Vasquez et al., 2015), processes of iron and steel production (Olmez et al., 2016) and different chemical routes in perfume production (Martinez-Guido et al., 2016). LCA applications pertaining utilization of renewable resources included large-scale production of biodegradable polymers (Kozlovskiy et al., 2017), biodiesel production from soybean in Brazil (Esteves et al., 2016), bio-oil production from fast pyrolysis and hydrothermal liquefaction of oil palm empty fruit bunch (Chan et al., 2016), and anchovy canning industry (Laso et al., 2017).

Large-scale sustainability of the different biomass co-firing options for real power system was analyzed by Kazagić et al. (2016). The study used multi-criteria sustainability assessment and single criterion analysis to investigate possibilities and sustainability of "biomass for power" solutions for a coal-based power utility. An integrated assessment model for the German food-energy-water nexus was presented by Schlör et al. (2018). Marton et al. (2017) presented a case sudy in which the steam utility network of a refinery was modelled to evaluate Heat Integration retrofit options proposed for the industrial site. The correct application of discounted cash flow methodology for evaluating and designing energy and chemical production plants was presented by Novak Pintarič and Kravanja (2017). Kasurinen et al. (2017) presented the switch from sustainability-as-usual to sustainability excellence in local bioenergy business. The study showed that for a shift of business, a systemic approach can be used to broadly identify sustainability questions and a multitude of methods by which the questions can be answered. The sustainable and green construction was investigated by Rosa et al. (2017). The study showed that the combined utilization of the functional resonance analysis method and analytic hierarchy process makes it possible to recognize situations where construction developments could potentially be without control; the gained knowledge provides a basis for a monitoring system. For the building sector and its energy supply and consumption, Kilkis et al. (2017) proposed a Rational Exergy Management Model which facilitates attaining a more efficient and cleaner energy supply structure.

Seen as a whole, the papers from previous SDEWES conferences clearly show that there is still a need for further research within all of the reviewed topical fields.

3. Research themes and areas represented in this Virtual Special Issue

After the review process, 22 papers from SDEWES 2016 Conferences were selected for this VSI. The main ideas of these papers that are among the best articles presented at the conference are briefly reviewed in the following subsections.

3.1 Energy issues

Papers reviewed in this subsection illustrated the complexity of the current issues of energy systems including interlinked roles of rational energy use and carbon dioxide reduction in various sectors of the economy, as well as fossil and renewable energy resources.

In the iron making industry, iron-ore sintering process is responsible for a significant part of the industry's energy consumption and GHG emissions. By using biomass for partial replacement of solid fuel (typically, coke breeze) in iron-ore sintering, the emissions can be reduced; however, the sinter strength may be weakened due to the changed heating pattern, especially at high biomass proportion. In the paper by Cheng et al. (in this VSI), the injection of gaseous fuel into lab-scale sintering bed was experimentally investigated as a method to solve that problem. Heating pattern and sintering effect in the base case (coke breeze as the only fuel) were compared with the effects of processes carried out at

20%, 40% and 60% charcoal replacement for coke breeze, augmented with combustion of methane supplied at ultra-low concentration (0.1-0.5% methane in air). The temperature distribution in the sintering bed was determined by both thermocouple measurement and infrared thermography.

It was observed that the methane/air mixture approaching the zone of solid fuel combustion was preheated by hot ore particles, then ignited to create a self-sustained zone of gaseous fuel combustion. The measurement results showed that due to improved heating pattern, the sinter strength kept increasing until the methane concentration reached 0.4-0.5%. At a high charcoal proportion in the solid fuel, considering the sinter strength, yield, productivity and sintering time, the recommended methane concentration of 0.5% resulted in the reduction of solid fuel rate by 7.52%, compared with 100% coke sintering case. In future industrial-scale applications, methane can be replaced – practically at no cost - by flammable waste gas discharged from the steelmaking process. Moreover, reduced consumption of solid fuel can be expected to contribute to a reduction in dust emission from the ore sintering process.

Due to progressing depletion of conventional oil and gas resources, offshore production of these energy carriers becomes more and more important, and drilling platforms are moving from shallow to deep and ultra-deep waters. Floating Production Storage and Offloading platforms are preferred in such frontier offshore enterprises. However, the processing of ultra-deep waters natural gas imposes challenges in the design of floating production units (FPUs), limited in area and weight of processing equipment. In this context, Reis et al (in this VSI) discussed exploration of oil reserves with a high gas/oil ratio (above 250 m^3/m^3) and high carbon dioxide content. Such oil reserves create additional challenges due to the impacts in the deck area of the gas plant because in addition to other operations of natural gas processing, removal of carbon dioxide in skid-mounted membrane modules is required to meet sales gas specification. To avoid emissions and to increase oil production, the separated acid gas is injected back for enhanced oil recovery, implying that carbon dioxide content in the reservoir will be increasing during production lifetime.

In searching for an appropriate concept of the gas upgrading section of the FPU, the authors developed mathematical models making it possible to optimize the arrangement of membrane modules and their operational conditions. The total membrane area was searched for minimum footprint of membrane skids, considering carbon dioxide content in the treated natural gas less than 3 mol% (Type 1 Constraint) or carbon dioxide content in the injection gas greater than 75 mol% (Type 2 Constraint). The optimization results included total and stage area of the membranes, carbon dioxide contents in retentates and permeates, and natural gas production. Numerical results were obtained for three feed scenarios: 10, 30 and 50 mol% CO_2 in raw natural gas. Type 1 Constraint leads to higher methane losses while Type 2 Constraint necessitates the application of Chemical Absorption as an additional polishing process. Considering life cycle costs and total footprint area of the gas upgrading section, the latter design concept was found to be more practical for time-varying composition of the raw natural gas. CO_2 separation in a single-stage membrane arrangement was proposed as a solution satisfying the requirements of the early or midterm operation period of project lifetime when gas feeds have lower or medium CO_2 content. A Chemical Absorption subsystem to support membrane separation arrangement during the period of the highest CO_2 content was suggested.

The renewable energy industry is one of the fastest growing industries worldwide, being one of the top 5 industries in 2015 in terms of the amount of investment allocated. This was reflected in a number of papers concerned with renewable energy technologies and their applications. Two contributions were devoted to gaseous energy carriers including ones produced from renewable resources. In the paper by Panjičko et al. (in this VSI), anaerobic digestion of brewery spent grain (BSG) was studied. BSG is a substrate consisting largely of cellulose, hemicellulose and lignin, which are difficult to degrade anaerobically, mostly due to process inhibition by lignin degradation products, such as phenolic compounds. A two-stage system was used for anaerobic digestion employing a solid-state anaerobic digestion reactor, where microbiological hydrolysis and acidogenesis occurred, and a granular biomass reactor where methanogenesis was performed.

The performance of the overall process was characterized by total solids degradation efficiency between 75.9 and 83.0%, average specific biogas production 414±32 L/kg and biomethane production 224±34 L per kg of added total solids. The presence of inhibitory phenolic compounds was confirmed by p-cresol concentrations up to 45 mg/L. During the process, however, these compounds were successfully degraded. Microbiological tests proved the structure of the bacterial community from granular biomass reactor and solid-state anaerobic digestion reactor remained 79.4 % similar at the end of the experiment, whereas archaeal community was only 31.6 % similar. Stable process operation was achieved during the test period of 198 days, which confirmed suitability of the two-stage system for biogas production from BSG.

The paper by Di Marcoberardino et al. (in this VSI) discussed the achievements of three European projects (FERRET, FluidCELL, BIONICO) devoted to the application of the membrane reactor concept to hydrogen production and micro-cogeneration systems using both natural gas and biofuels (biogas and bio-ethanol) as feedstock. Membrane reactors for hydrogen production can increase both the hydrogen production efficiency at small scale and the electric efficiency in micro-cogeneration systems when coupled with Polymeric Electrolyte Membrane (PEM) fuel cells. The membranes, used to selectively separate hydrogen from the other reaction products (CH_4, CO_2, H_2O, etc.), are of asymmetric type with a thin layer of Pd alloy (<5 μm), and are supported on a ceramic porous material to increase their mechanical stability.

In the FERRET project (A flexible natural gas membrane reformer for M-CHP applications, 2014-2017), the flexibility of the membrane reactor under diverse natural gas quality was validated. The reactor was integrated in a micro-CHP system and a net electric efficiency of about 42% (8% points higher than the reference case) was achieved. In FluidCELL (Advanced m-CHP fuel CELL system based on a novel bio-ethanol Fluidized bed membrane reformer, 2014-2017), the use of bio ethanol as feedstock for micro-cogeneration PEM based system was investigated in off-grid applications and a net electric efficiency around 40% was obtained (6% higher than the reference case). Finally, the ongoing BIONICO project (Biogas membrane reformer for decentralized H_2 production, 2015-2019) investigates the hydrogen production from biogas. It is aimed at developing, building and demonstrating (at a real biogas plant) a novel reactor concept to integrate H_2 production and separation in a single vessel. The planned hydrogen production capacity is 100 kg per day.

In view of the needs of the transportation sector, liquid energy carriers and their production from renewable resources are topics of continuing interest. Hajek et al. (in this VSI) reported the results of their research on new materials that can be used as catalysts for conversion of vegetable oil into biodiesel. Mg-Fe hydrotalcites with a constant molar ratio (Mg/Fe 2.5:1) were synthesized from two types of precursors (chlorides and nitrates of metals) and thermally pre-treated at different temperatures (500 and 600 °C). It was found that the crystallite size of hydrotalcite increases with an increasing aging time. The synthesized materials were characterized by several techniques such as X-ray Powder Diffraction, thermogravimetric analysis with a mass spectrometer, the determination of specific surface area, pore size distribution and basicity of oxides and after that, tested in the transesterification of rapeseed oil.

It was found that crystallite size, amount of the crystalline phase and specific surface area were almost the same for both precursors. After calcination, the mixed oxides from the nitrate precursors revealed higher amount of basic sites and population of stronger basic sites than those obtained from the chloride precursors. The rehydration, i.e. the restoration of a layered structure, successfully proceeded for hydrotalcite synthesized from nitrates calcined at 500 °C. However, in the case of chlorides, the hydrotalcite had to be calcined at 600 °C so that the rehydration was successful. The application of materials synthesized from chlorides resulted in a lower conversion (25 %) than that of materials synthesized from nitrates (60 %).

Traditional routes of biodiesel production include using methanol - a fossil based chemical – as transesterification agent. As a possible measure to improve biodiesel renewability, governmental policies and subsidies to promote the substitution of methanol are considered in some countries. In their work on Brazilian soybean biodiesel scenario, Interlenghi et al. (in this VSI) compared the methylic and ethylic production routes to unveil whether ethanol-based biodiesel could be more promising from the viewpoints of social and environmental aspects of sustainability. In order to make a convincing comparison possible, a database was constructed by compiling the characteristic parameters of the fatty acid methyl ester (FAME) and fatty acid ethyl ester (FAEE) soybean biodiesel production chains, and `by quantifying energy and material flows. After that, Multi-criteria Analysis and Principal Component Analysis (PCA) were applied for data interpretation and identification of the most relevant factors affecting sustainability. In applying Multi-Criteria Analysis, quantitative indicators were combined with principles of green process design and processed to provide a one-dimensional index called Sustainability Degree (Araújo et al., 2015).

It was proved that due to social factors, more severe conditions of the transesterification process and extra transport demand, fatty acid ethyl ester is generally less sustainable than the methylic counterpart. In addition, PCA indicated average personnel costs, water intensity and carbon intensity as the influential indicators, more important than energy consumption. Contrary to common beliefs, it was shown that the importance of social factors to the determination of sustainability level cannot be neglected, and soybean-based biodiesel production via FAME route has more potential to be sustainable than that via FAEE route.

Due to their abundance and suitability for conversion into clean electricity, solar energy and wind energy have attained the status of strategically important renewable resources. Libertini et al. (in this VSI) discussed the design of a Solar Assisted Combined Cycle (SACC) power plant based on a solar loop equipped with a double stage absorption chiller driven by high-temperature high-vacuum non-concentrating flat-plate solar thermal collectors. The solar loop is coupled to a single-pressure Combined Cycle power plant and the cooling action of the absorption chiller is used to cool gas turbine inlet air, thereby enhancing system efficiency and electrical capacity. The operating temperatures of solar collectors are sufficiently high to drive a two stage absorption chiller whose Coefficient of Performance is roughly twice as high as that of a conventional single stage absorption chiller.

In order to evaluate the technical (including energy aspects) and economic feasibility of this technology, especially for applications in hot and dry areas, the SACC arrangement was analysed through dynamic system simulation in TRNSYS software environment and thermoeconomic analysis. Equipment characteristics and costs were determined using ASHRAE and ISO standards and manufacturers' data. Aiming at the maximum utilization of solar energy for cooling purposes, a special control strategy for managing cooling water flow was implemented to limit, as much as possible, water condensation within the cooling coil. The thermoeconomic model included system capital and operating costs as functions of design and operating parameters. A simulation study was performed assuming system location in Almeria, southern Spain, whose hourly weather data files were obtained from Meteonorm database. The simulations results showed that a very high thermal efficiency of solar collectors, on average equal to 34%, could be achieved. The calculated economic indices were found to be satisfactory and the pay back period was about 8 years in the best case.

For decades, the renewable energy sector has been supported by the governments through various economic, regulatory, and political support policies. However, in the developing countries that lack own investment capital, exploitation of renewable energy resources depends on the allocation of foreign direct investment (FDI) in the sector. As the situation is widely differentiated between the developing countries, Ryota Keeley and Ikeda (in this VSI) studied the effects of governmental support policies on FDI as location determinants, focusing on wind energy. A comparison was made with the effects of the widely accepted institutional and macroeconomic determinants such as corruption level, price stability, access to finance, and GDP growth. Information found in the pertinent literature, as well as statistical data on the economies (including FDI) of developing countries available from international institutions (OECD, IMF, IEA) and specialized service companies (GlobalData, fDi Intelligence) were gathered and analysed employing such methods as Exploratory Factor Analysis and Structural Equation Modelling.

The results of the study showed that renewable energy support policies have equivalent or greater effect compared to the institutional and macroeconomic determinants. The importance was also demonstrated of analysing FDI determinants focusing on a specific sector rather than looking at overall foreign direct investment. Among policy implications to attract FDI into renewable sector of the developing countries, the need was highlighted for improving the regulatory aspects of that sector such as guaranteed access to grid infrastructure, trade openness, and easing general investment restrictions.

3.2 Water issues

The access to fresh water and sanitation is an issue of global concern, with specific features that may vary depending on the geographical location as well as on the level of socioeconomic development of individual countries. Although it can be regarded as a water-rich country, Russia faces a number of substantial administrative and structural issues in the water sector and therefore, a long-term strategy for the management of this strategic resource is needed. The paper by Proskuryakova et al. (in this VSI) outlined long-term scenarios and strategies for the Russian water sector until 2030. Building upon an earlier study on global trends and uncertainties related to water sector, and using a combination of foresight methods including scenario analysis, data mining, and various expert methods, alternative futures for the Russian water sector were considered. The developed scenarios were characterized by qualitative and quantitative factors and indicators of future developments in three key domains for the water sector: sustainability of water systems; water use by households and industry; and new water products and services. Four alternative trajectories of the development of the water sector in Russia were presented. Among the scenarios worked out, „Problem conservation" (approximately, Business as usual) and „Losses and accidents" (approximately, Inadequate progress) were identified as the most probable ones. Possibilities to revert these scenarios into more desirable trajectories were also discussed; for instance, if new clean water technologies were widely applied, then a visionary scenario named „Nearly perfect future" could be attained.

Over the years, measures to reduce water use have been implemented in various industries including coal-fired power plants. In this line of action, the paper by Xiong et al. (in this VSI), summarized the results of investigation of water recovery, combined with heat recovery, from low-temperature flue gases exiting a limestone-gypsum wet desulfurization system. In order to avoid problems with the equipment operated in a highly corrosive environment, a pilot-scale prototype system comprising a two-stage fluorine plastic heat exchanger (FHE) was installed in a 660 MW lignite-fired power plant in northern China. The operating principle of the system is based on the condensation mechanism of water vapor. As the fluorine plastic is resistant to acid corrosion, the FHE can overcome the shortcomings of the conventional metal heat exchangers, especially when flue gas temperature is below the acid dew point.

According to the results of measurements done during test operation, the recovered thermal power was about 92 MW of which more than 80 % was due to the heat of vapor condensation. The efficiency of water recovery was found to increase with an increase in cooling water velocity and a decrease in flue gas velocity, and efficiency value higher than 70 % was reached when the flue gas velocity was less than 5 m/s and the cooling water velocity was above 0.24 m/s. The highest water recovery efficiency of the two-stage FHE was 85 %, suggesting that this technology has an application potential in various industrial processes. The mass of water recovered from the flue gas by condensation was nearly equal to, or even exceeded, the mass of supplemental water consumed by the desulfurization system. This paves the way for achieving zero water consumption in power plants equipped with desulfurization systems supplemented by FHE-based water & heat recovery systems. Potential water savings are of great significance for power plants, especially ones operated in water scarce regions.

Efficient wastewater treatment is a factor of highest importance to maintaining a healthy environment and to securing adequate water balances of industries, municipalites and regions. In this context, further progress is needed in the development of reliable water treatment technologies including ones that can eliminate refractory chemical compounds such as 2,4-dichlorophenol. Its presence in wastewaters resulting from the use of crop protection chemicals, it is a toxic and difficult-to-degrade pollutant. In the paper by Van Aken et al. (in this VSI), experimental research was reported on the effect of pre-ozonation of synthetic wastewater spiked with 2,4-dichlorophenol prior to a biological treatment in pilot-scale bioreactor. It was found that pre-ozonation may lead to the formation of intermediate products that are not completely biodegradable. However, indications were observed of a positive effect, that is, enhanced sludge settleability while the nitrification and denitrification process was not affected.

As an unwanted by-effect of the continuing development and market introduction of new chemical products, new pollutants may penetrate the environment posing new risks to the environment including water reserves in its aquatic part. The combustion of liquid fuels – first of all, heavy oils – leads to the formation of pollutants including nitrogen oxides (NOx), sulfur dioxide and hydrocarbons. The emission of such pollutants can be reduced by means of special fuel additives including a modifier based on fatty acid ferric salts dissolved in fuel oil (May and Hirs, 2005). In the conditions of the combustion process, iron from ferric salts forms iron oxides which improve the fuels in terms of oxidation properties leading to the reduction of hydrocarbon, CO and NOx emissions; however, iron compounds are then emitted in the flue gases. As iron at high concentrations is known to be harmful to the aquatic environment, Guziałowska-Tic and Tic (in this VSI) investigated the effects of the iron-based modifier on the aquatic flora and fauna. The influence of modifier addition on algal growth inhibition, acute toxicity to rainbow trout, and reproduction of daphnia has been experimentally examined.

According to test results, modifier concentration capable of reducing the rate of algal growth by 50% after 72 hours was higher than 100 mg/L, and the mean concentration capable of killing 100% of the trout population after 96 hours (so-called lethal concentration for 100%) was higher than 320 mg/L. Depending on modifier concentration in water, the rate of reproduction of *Daphnia magna* dropped by 0.6% to 16.7%. This means that, although capable of affecting the aquatic flora and fauna, the iron-based modifier does so only when present in water at rather high concentrations. Since it is used as a fuel additive in small quantities only, it appears not to endanger the aquatic environment.

3.3 Environmental engineering and management

Apart from their possible effects on the aquatic environment, iron compounds – especially if present in high concentrations – can be dangerous to humans. Guziałowska-Tic and Tic (in this VSI - a) investigated also the effect of the iron-based fuel modifier on human health. The results of acute oral toxicity tests, acute skin irritation/corrosion tests in rabbit, and isolated chicken eye tests for identifying ocular corrosives and severe irritants have been analyzed. In the oral toxicity test and isolated chicken eye test, the iron-based modifier was found to be a non-hazardous substance, posing no risks to the human health. However, the results of the acute dermal irritation/corrosion test in rabbit indicated that the modifier is a skin irritant. Accordingly, in practical situations of handling the iron-based fuel modifier, particular attention should be paid to contact with the skin.

Coal-fired power plants are known as major sources of atmospheric emissions and solid waste. In the countries dependent on coal as the main fuel for power generation, systematic work is needed for adapting to increasingly stringent emission regulations. In the paper by Cao et al. (in this VSI), a novel technology for flue gas pre-treatment in coal-fired power plants was proposed to improve the removal of fine particles and trace elements from the gas. Using the results of research on wet particle removal, Brownian diffusion, diffusiophoresis, thermophoresis and disturbed gas flow in channels, an equipment piece called wet phase transition agglomerator (WPTA) was developed. As a demonstration project, the WPTA and the wet electrostatic precipitator were combined into a wet dust removal system (WDRS), and installed in a 660 MW ultra-supercritical power generating unit in China. During test operation, the concentrations of particles at WDRS inlet and outlet, as well as in the wastewater discharged from the system, were measured to evaluate system performance.

According to measurement results, WDRS helped to reduce ultra-low emissions of particles to the level below 5 mg/m^3. WPTA was found to contribute to system performance significantly because at boiler operating loads of 90% and 75%, compared to system operation without WPTA, the removal efficiency of total suspended particulates rose 4.01 and 3.17 percentage points, respectively, and at 90% load, the efficiency of PM1 removal was increased from 68.67% to 83.61%. WPTA was also found to enhance the removal of trace elements. Compared to system operation without WPTA, mass flows of Hg, As and Mn discharged in the wastewater were increased 4.2, 2.8 and 1.5 times, respectively.

As the investment and operation costs of emission control systems in coal-fired power plants are very high, engineering solutions are sought for easing the associated economic burden on power production. This applies also to the plants equipped with with semi-dry flue gas desulfurization (semi-dry FGD) systems that produce large amounts of solid residue contaminated with calcium sulphite. To convert this residue into material useful to, e.g. cement industry, and to avoid landfill disposal, the study by de Andrade Cruz et al. (in this VSI) suggested complementing semi-dry FGD by a residue treatment unit that promotes dry oxidation of calcium sulfite to calcium sulfate. After sizing the main equipment of this unit on the basis of pilot-plant data and patents, economic evaluation was elaborated of capital expenditure, operational and maintenance costs, and sale of the treated residue. This allowed the estimation of the levelized cost of produced electrical energy to assess the impact of the technology on the price of electricity from a power plant that uses the proposed residue treatment unit. As a base case, a Brazilian coal-fired power plant facing decision making process on semi-dry FGD waste destination was selected.

According to calculation results, the plant equipped with semi-dry FGD without the residue treatment unit, had total levelized cost of energy increased by 0.56% (from 94.44 to 94.97 USD/MWh) due to solid waste disposal. If the treated semi-dry FGD residue was transferred (at zero revenue) as additive to the cement industry, the levelized cost of energy of the power plant would remain approximately unchanged because the increase resulting from the investment and operation and maintenance cost of the treatment unit would be compensated by the avoided waste disposal costs. However, the commercialization of the treated semi-dry FGD residue as raw material would lead to a reduction of 2.83 USD/MWh (about 3%) in the levelized cost of energy (to 92.14 USD/MWh). In both cases, although the effect of the proposed treatment unit on the total power plant levelized cost of energy is insignificant, residue management problems of landfill saturation, land use and costs related to landfill maintenance would be solved. This justifies the implementation of the treatment unit for semi-dry FGD residue in the studied power plant and encourages considering application of such treatment units in power plants with similar design and economic parameters.

Certain waste streams may include materials that are difficult to process for recycling or valorization. This is exemplified by electronic and electrical waste containing brominated compounds (flame retardants) known for their dangerous properties including persistence, bioaccumulation, and potential for toxicity, both in animals and in humans. In the paper by Kim et al. (in this VSI), research on the processing of bromine-containing epoxy-printed circuit boards (e-PCBs) by catalytic pyrolysis was reported. The e-PCBs and thermoplastics, high density polyethylene (HDPE) and polypropylene (PP) were co-pyrolyzed over HZSM-5 and HY catalysts. The effects of catalytic co-pyrolysis were investigated using thermogravimetric analysis and gas chromatography/mass spectrometry.

The tests indicated successful elimination of the brominated compounds, mainly bromo-phenols and –bisphenol, however with elimination efficiency that was dependent on the properties of the thermoplastics and catalysts. The lowest bromine content in the pyrolysis gas was achieved when HDPE and HY(30), i.e. HY with SiO_2/Al_2O_3 ratio equal to 30, were used as the co-feeding reactant and catalyst on the pyrolysis of e-PCBs. The gas contained significant amounts of mono-aromatic hydrocarbons and mono-phenol, which can potentially be used as fuels or chemical feedstock.

In oil and gas drilling operations, large volumes of waste known as drill cuttings (broken bits of solid material soaked with drilling fluid) are generated posing a risk to the environment. The available technologies for treatment and final disposal of this waste material are differing in multiple aspects so that overall sustainability of the technologies is differentiated. In the literature on comparing sustainability of end-of-pipe technologies, the common approach is to use indicators that express the benefit of adding a waste management step. In this line of thinking, Almeida et al. (in this VSI) presented a methodology for sustainability analysis of solid waste management, adapted to the specificities of drill cuttings. This was illustrated by a case study in the area of oil-bearing geological formations (known as pre-salt area) on the continental shelf off the coast of Brazil. The methodology was meant as a tool for contributing to the decision-making process on drilling waste management. Performance of a given technology was evaluated by combining environmental, economic, safety and technical aspects in an original multi-criteria analysis employing Sustainability Degree (SD) index (Araújo et al., 2015).

The evaluated waste management technologies included: offshore discharge, onshore disposal, offshore cuttings re-injection and microwave treatment followed by onshore disposal. Process inventories were compiled and used in the calculation of the SD index for ranking of alternatives. From the ranking, the offshore discharge of drill cuttings was identified as the most sustainable among the evaluated technologies, followed by microwave treatment, onshore disposal and offshore re-injection.

Consumption habits and population growth have drastically increased the generation of municipal waste around the world. This leads to acute environmental problems in some developing countries where no adequate waste management systems are available. In planning such systems, decisions are needed on the design of waste processing facilities, sustainable public policies, cooperation among multiple cities, etc. In the paper by Santibañez-Aguilar et al. (in this VSI), a mathematical formulation was proposed for the optimal planning of a waste management system considering both waste from different neighboring cities divided in several sites, and the time dependence for the variables and parameters. The input data were assumed to include potential locations for sites, landfills, processing plants and consumers, as well as prices of useful products, availability of waste, upper and lower limits, unitary costs for the different activities carried out in the waste management system and initial values for inventory and order levels. Using economic criteria, the model allows to determine the optimal selection and location of the entities of the waste management system as well as capacities of processing plants and material flows to be transported, processed, stored and sold. The proposed mathematical formulation can be applied to any waste type, involving different landfills, sites, cities, processing routes and processing plants.

The model was applied to a case study in a Mexican region which consists of 5 cities divided in 10 sites each; the region includes 10 processing facilities and 20 landfills. Collection, storage and processing of five types of waste and several types of subwaste were considered. The main results were presented as a Pareto curve for the consumed waste and the net annual profit, and economic characteristics were identified for each Pareto-optimal solution of the waste management system.

3.4 Sustainable engineering solutions and large-scale sustainability approaches

The chemical industry contributes to the environmental impacts mainly due to the use of non-renewable feedstocks and inefficient use of mass and energy. This leads to excessive generation of waste and atmospheric emissions, especially carbon dioxide, which contributes to global warming and climate change. Rather than treating carbon dioxide as waste, it can be regarded as an alternative chemical feedstock for the synthesis of fuels and chemicals, enabling reduction of the industry's dependence on petrochemicals. The paper by Machado et al. (in this VSI) evaluated the utilization of carbon dioxide as feedstock to the production of chemicals in an industrial park to reduce environmental impacts of a sugarcane biorefinery. The environment-oriented chemical complex comprising seven production plants, named Eco-Pole, would aim to increase the sustainability of the sugarcane bioethanol industry located nearby the complex, using also both carbon dioxide produced in sugarcane fermentation and bioethanol itself as feedstocks. The main advantage of Eco-Pole would be in the availability of high-purity carbon dioxide to produce chemicals traditionally derived from fossil raw materials, namely methanol, propylene, ethylene, ethylene oxide, propylene oxide, ethylene carbonate, propylene carbonate, dimethyl carbonate and ethylene glycol.

Using Aspen HYSYS software, process simulation was carried out to determine mass and energy balances to support the calculation of quantitative performance indexes (including net carbon dioxide emissions, energy intensity and water intensity) making it possible to compare efficiencies of the individual processes arranged in the Eco-Pole. The ethylene oxide plant showed best economic performance, while the worst performance was found for the propylene unit. A multi-criteria analysis ranking sustainability performance identified the the propylene plant as the poorest performer. The estimated cash flow of the Eco-Pole indicated deficient economic performance, but with profitability potential that could be unveiled by optimizing configuration of the entire industrial complex. Nevertheless, the indexes of raw material and energy consumption of the Eco-Pole were satisfactory, and due to synergy between the production plants, specific carbon dioxide emissions of Eco-Pole products were found to be relatively low.

In the paper by Saez et al. (in this VSI), environmental characteristics of the applications of a novel aerogel based panel as a component of building insulation were studied. Taking advantage of nanotechnology, panel lifetime is increased while the thickness, in-building installation time and cost are reduced in comparison to conventional insulating materials such as Expanded Polystyrene, Extruded Polystyrene and Mineral Wool. Due to its low thermal conductivity of 0.015 W/(mK), aerogel based panel 10 mm thick achieves a thermal insulation effect equivalent to 25 mm thickness of standard Expanded Polystyrene Panel. The study assessed the life-cycle environmental implications linked to the improvement in the energy efficiency of buildings resulting from the application of nano-technological aerogel based panel insulation. A cradle to grave approach was adopted for the environmental evaluation of the product life-cycle, including its integration into an existing residential building and its insulation performance during building´s use phase.

The developed model was fed with the data of 5 European climate zones, to evaluate both the performance of thermal insulation under different weather conditions and the effect of varying insulation thickness. The environmental impacts were also evaluated depending on the heating source used, and the comparison with other traditional insulation materials was worked out. In all the studied weather scenarios, net life-cycle environmental benefits were found for the applications of the aerogel based panel. Its advantages including minimization of space occupied by the insulation are clearly visible when the passive house requirements of façade thermal insulation are considered with thermal transmittance values in the range between 0.1 to 0.15 W/(m²K). This implies the novel product is suitable for the retrofit of existing buildings by both, external or internal thermal insulation.

In coping with the harmful consequences of climate variability, business organizations and economy sectors need to consider both measures to avoid economic losses and adaptive modifications to improve production processes. In view of negative effects of climate change that are predicted to affect the agriculture incoming decades, wine sector deserves special attention as it is extremely vulnerable to climatic risks. However, due to complex interrelations between a number of socio-economic and environmental variables, this sector lacks appropriate adaptation strategies. In order to close the knowledge gap, Sacchelli et al. (in this VSI) presented a decision support system to identify adaptation strategies for wine farms undergoing climate change, through analysis of a wine farm's economic performance when it adopts measures to cope with climatic variability. Average values of parameters characterizing climate change and extreme events were considered to assess different scenarios. A mix-method (metaheuristic) approach was applied to integrate probability calculations, complex system analyses and operational research.

The resulting model was tested on a case study located in central Italy (Chianti Classico). To maintain and improve future financial performance, organic farming and adjustments to procedural guidelines were recommended as key strategies. Economic variables, such as the average price of wine, were found to have a strong influence on farms' implementation of adaptive measures. As an additional result, insurance schemes in areas producing high quality wine were suggested to include availability of low-level deductibles and public funding.

As a key ingredient of the sustainable development, resource efficiency is about using the Earth's resources (metals, minerals, fuels, water, land, timber, fertile soil, clean air) in a sustainable manner to satisfy society needs, producing more value with fewer resources, lessening environmental impact and rationalizing consumption. It is an essential priority of the Europe 2020 Strategy and the associated Flagship Initiative for a resource efficient Europe. In order to evaluate the progress of the European Union towards the objectives of the Flagship Initiative, the paper by Moreno and García-Álvarez (in this VSI) benchmarked the 28 EU member states using so-called Resource-Efficiency Capacity Index (RECI). This composite index was based on the calculations of 29 indicators, which were grouped in three dimensions. The first dimension benchmarked EU-28 members according to the promotion of waste recycling, to the support of research and innovation in resource efficiency and to the implementation of environmental taxation. The second dimension benchmarked the countries according to energy efficiency in residential buildings and the third dimension - according to the development of more sustainable transport modes. The three dimensions were aggregated for a final ranking.

Using statistical data for 2013, Denmark was indicated to receive the highest ranking with a composite index value of 3.35, followed by Sweden (3.22) and Finland (3.13). The establishment of more effective policies was recommended to the member states with the lowest RECI scores: Slovakia (1.8), Malta (1.92) and Poland (1.93). It was also concluded that despite considerable progress made towards resource efficiency in the last decade, the EU needs to intensify the promotion of life-cycle thinking to increase waste recycling, to make public passenger transport more attractive, or to increase the energy efficiency of residential buildings.

4. Concluding remarks

This VSI of the JCLEPRO, dedicated to the 2nd SEE SDEWES and 11th SDEWES Conference, gave an overview of topics related to sustainable development and cleaner production. The authors of this article believe that the selected papers and addressed issues will considerably extend the knowledge body published in JCLEPRO and will be of interest to its readers. The selected papers describe recent advances, and provide insights into future development, in four main fields that are of strategic importance to the sustainable development: energy issues, water issues, environmental engineering and management, sustainable engineering solutions and large-scale sustainability approaches.

Future SDEWES Conferences will build upon the potential of presenting new practical experience and disseminating new knowledge on shaping the future by building upon the pillars of sustainability. Information on the upcoming events and other related activities can be found on the website of the International Centre for Sustainable Development of Energy, Water and Environment Systems (SDEWES Centre).

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