Editorial: The special issue of ENERGY - The International Journal dedicated to the 6th International Conference on Polygeneration (ICP-2021)

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This Special Issue of ENERGY devoted to the Sixth International Conference on Polygeneration (ICP 2021) contains selected papers presented in this conference. ICP 2021 has been organised by the Thermal Engineering and Energy Systems research group (GITSE), pertaining to the Aragon Engineering Research Institute of the Universidad de Zaragoza, Spain, in collaboration with the Universitat Rovira i Virgili, Spain. It is the sixth edition of the International Conference on Polygeneration series (http://www.polygeneration.net/) that started in 2007 as 1st European Conference on Polygeneration, held in Tarragona, Spain and organised by the Universitat Rovira i Virgili.

Polygeneration conferences aim to contribute to address the challenge of creating a more sustainable future for world's energy needs by applying an integrated approach towards Energy Efficiency measures combined with the increased use of Renewable Energy Sources on a local level. More specifically the last edition of the International Conference on Polygeneration (ICP 2021) was committed with the challenge of contributing to the reduction of greenhouse gas emissions in order to achieve by 2050 net-zero CO_2 emissions at global level.

In this respect, polygeneration systems can play a key role since they refer, thanks to an efficient energy process integration, to the combined production of electricity, heat, cold and any other useful products such as potable water, dry air, biofuels and/or synthetic fuels, among others.

In this special issue relevant aspects concerning polygeneration systems as a tool to enable an effective way to achieve a lower consumption of natural resources, a reduction of greenhouse gas emissions and pollutant emissions as well as economic savings relative to conventional separate production, are envisaged.

Thus, the 15 selected papers deal with relevant aspects of polygeneration systems such as:

i) energy storage considering different technologies of energy storage - thermal energy storage, thermochemical, hydrogen and combination of technologies,
ii) advanced heat pumps,
iii) integration of renewable technologies in energy provision systems, and
iv) policy and managerial aspects.

In addition, this special issue is opened with an excellent paper from Prof. Groll [1] in which is presented a proposal about how to avoid climate change, that we are already experiencing, prior to irreversible and very likely dramatic consequences to the environment will be suffered. Prof. Groll, presents a vision about a feasible hydrogen-electricity future economy, essentially based on renewable energies as the primary energy sources and on hydrogen and electricity as secondary energy vectors, and explains key aspects for this transition in order to in order to keep the average temperature rise of the atmosphere below 1.5 ºC, over the pre-industrial level, until the end of the century.

Next, are presented five selected papers dealing with energy storage.

Malleswararao et al. [2] studied with COMSOL Multiphysics® the thermal behaviour of an energy storage system consisting of Mg_2Ni-$LaNi_5$ pair of metal hydrides that can serve as thermal energy storage in long-term (operating between 300 ºC and 25 ºC) and buffer (operating between 300 ºC and 230 ºC) modes of operation as well as hydrogen storage. Several aspects were studied in detail, e.g. the variations in porosity and density of hydride beds with hydrogen concentration during charging and discharging processes; and the effects of heat source temperature and the hydrogen storage bed temperature on the thermal performance of the system. The influence of hydrogen storage bed temperature was significant particularly in buffer operation. The energy density storage achieved was significant being, with the heat source at 300 ºC, of 532.64 MJ m^{-3} with 67.8% efficiency in long term energy storage and of 430.28 MJ m^{-3} with 91.2% efficiency in buffer mode.

Thermal energy storage using upgraded low temperature heat was studied by Ding et al. [3] that presented a novel absorption-based compression-assisted energy storage heat transformer (CESHT) able of reducing the charging temperature, improving the energy storage performance and enhancing the ability to upgrade the temperature. The dynamics of this novel system was analysed and compared with basic absorption-based energy storage heat transformers (ESHT). The effects of heat output, heat input and heat sink temperature have been investigated. Significant enhancements have been achieved by the proposed novel CESHT cycle for both energy storage performance and temperature upgrading ability. With auxiliary compression, the temperature lift is increased from 30 ºC to 65 ºC, and the required input temperature is decreased from 60 ºC to 45 ºC. Moreover, the performance indexes were greatly improved, e.g., the energy storage efficiency, energy storage density, and exergy efficiency increased respectively from 0.24 to 0.43, from 35.2 kWh/m^3 to 282.7 kWh/m^3, and from 0.32 to 0.54 with a temperature lift of 30 ºC.

Kumar and Muthukumar [4] studied the effect of methane as gas impurity in metal hydride hydrogen storage systems. Methane as an impurity showed significant bed poisoning characteristics. In particular, they studied experimentally the effect of methane in $La_{0.9}Ce_{0.1}Ni_5$ based Metal Hydride Hydrogen Purification System by varying the impurity level between 10% and 50% by weight, in the H_2 gas mixture and by performing cyclic test with 10% impurity. A prototype reactor with 6 embedded cooling tube was built. The experimentation comprised of three steps i.e. absorption, flushing and desorption of gas mixture. The system delivered 99.9995% pure hydrogen for 10–20% impure gas mixture. The regeneration of the poisoned “Metal Hydride (MH)” bed was performed in two regeneration cycles. The bed poisoning can be decreased significantly, if the desorption temperature is maintained above 90 ◦C.

Pavangat et al. [5] studied the techno-economic feasibility of a mobile thermochemical energy storage using LiCl as the thermochemical energy storage material for the utilization of the waste heat of the Rourkela Steel Plant for the cooling system (300 Ton of refrigeration) of a building of the National Institute of Technology of Rourkela, which is located at a distance 7.4 km from the steel plant.

Sharma et al. [6] developed an optimised polygeneration system consisting of solar PV field microgrid with electrolyzer, fuel cell, metal hydride hydrogen storage and electric batteries and studied its performance along the year in five different climatic zones of India. The optimization aims to maximise the utilisation of the electricity produced by the PV field. By introduction of metal hydride hydrogen storage together with fuel cell and electrolyzer, the microgrid delivers multiple outputs in addition to electricity, such as heat, H2 fuel and water. The thermal output from metal hydride contributes to more than 50% of total thermal load across different considered zones. Thanks to the hydrogen energy system, the polygeneration microgrid converts at least 30% of surplus electricity produced from PV into useful energy output. The effectiveness of polygeneration microgrid is clearly felt in mountainous, humid subtropical and arid climates. It is also moderately influential in tropical wet and dry climates.

In the field of advanced heat pumps the next three papers were selected.

Navarro-Esbrí et al. [7] presented a semi-empirical study of a two-stage cascade cycle for High Temperature Heat Pump (HTHP) applications to produce hot water up to 150 ºC from a water flow at 35 ºC and 25 ºC. The work was developed using experimental results of two single-stage heat pump prototypes (R-1234ze(E) and R-1336mzz(Z)) with different temperature lifts. The energy performance of the proposed two stage cascade HTHP was evaluated through a semi-empirical model, including novel mixtures of refrigerants for both stages. Up to 14% of COP increase was reached respect to the baseline when using R-152a/600 (0.08/0.92) and R-1233zd(E)/161 (0.88/0.12) for the low stage and high stage, respectively. Direct CO2e emissions were negligible by using low Global Warming Potential refrigerants. Nevertheless, indirect CO2e emissions are highly dependent on the technologies involved in the electricity production of the grid. Thus, in countries with carbon emission factor of the electricity grid lower than 0.35 kg CO2e/kWh the mixtures selected would reduce the emissions compared to fossil fuel boilers for the same thermal energy production.

Ayou et al. [8] proposed a novel reversible water/LiBr absorption heat pump connected to a district heating network for space cooling, heating, and domestic hot water (DHW) of a typical small-office building located in two cities (Barcelona and Berlin) with different climate conditions. The district heating network provided the driving heat of the reversible absorption heat pump. The dynamic modelling and simulation of the absorption heat pump driven by the district heating network were carried out for each operational mode. The annual heating COP of the proposed absorption heat pump was about 1.454 in the case of Berlin and around 1.667 in the case of Barcelona. In the cooling mode, the COP was between 0.79 and 0.81. Due to the reversible operation the proposed system had an increased operation time up to 63% with respect to non-reversible heat pumps and consumed less primary energy with a reduction of up to 30%.

The work developed by Kumar et al. [9] combines the integration of renewable energies (biomass) with an advanced ammonia-water absorption heat pump with parallel evaporators for different cooling options and power production, for the rural village of Athanavoor in India. Net power output can be increased either by decrease of the pumping power or increase of the pressure ratio. Thanks to two absorbers incorporated in the advanced absorption cycle can be provided these advantages. The rejected heat is utilised either for fresh water production, drying or domestic hot water applications. The behaviour of the system was analysed considering the influence of medium pressure absorber temperature, generator temperature, condenser temperature and the refrigerant flow to cooling and power sub cycle. The maximum resource utilization efficiency and system exergy efficiency of the advanced absorption polygeneration was about 22.46% and 12.26% respectively at a typical operating condition with the generator temperature of 230 ^{o}C.

The next four papers dealing with integration/promotion of renewable technologies in energy provision systems were selected.

The integration of organic Rankine cycles within residential solar thermal installations, which is an interesting opportunity for local cogeneration based on synergies with existing thermal heating and storage systems, is analysed in the work developed by Rodriguez-Pastor et al. [10]. More specifically it is evaluated the potential for the integration of hybrid solar organic Rankine cycles in residential buildings. The analyses are focused on the annual yields of a domestic 1 kW organic Rankine cycle cycle to assess the advantages and disadvantages of the variation of demand and the availability of solar resources. Steady state and dynamic models were developed, integrating TRNSYS® and EES® to allow a detailed evolution characterisation. The proposed system reduces the overheating associated with the lack of heat demand and excess solar irradiation in the solar system for the warm months by 20%, obtaining interesting economic results.

Atienza-Marquez et al. [11] evaluated several measures to promote the solar contribution of DHW production in a medium size hospital located in Vélez-Málaga, Spain. The developed work is very interesting since hospitals consume large quantities of energy to produce hot water. The authors developed first and energy audit of the hospital containing a solar thermal system combined with gas boilers for domestic hot water production in a medium-size hospital. The solar contribution to the total demand (27%) was significantly below design expectations (75%), resulting in an important additional gas consumption. In order to reach a solar fraction of 60% a techno-economic evaluation of energy retrofit measures was performed. The cost-optimised solutions required the enlargement of the solar caption area by 43–57% and improved insulations to reduce thermal losses by 70%. Depending on carbon taxes, the cost of hot water production could be about 31–41 cent-€/kWh, which represents a 15–45% reduction from the current costs. Implementing stringent climate policies, installing heat pumps may further enhance economic competitiveness. Moreover, useful indicators and charts for decision-making concerning the energy refurbishment of solar domestic hot water systems, are presented in this paper.

Ng et al. [12] deal with the important environmental problem of reducing the pollution of palm oil mill effluents by developing an optimisation model for the synthesis of a sustainable production of bio-methane from the previously referred effluents based on economic and environmental performances. A multi-objective optimisation approach (fuzzy optimisation approach) is adopted in the optimisation model to trade-off the objectives. The model is applied to a typical 60 t/h of fresh fruit bunches palm oil mill in Malaysia with Integrated Anaerobic-Aerobic Bioreactor at 45 ºC and cryogenic separator are selected to produce 90 wt% of bio-CH_4 from the palm oil mill effluents.

The Brazilian Energy Matrix is characterised by the presence of Renewables, whose participation reached 46.1% in 2019, of which 18.0% represented the sugarcane biomass share. The sugarcane industry is energy self-sufficient, i.e. all the energy consumed comes from sugarcane and their products. Furthermore, sugarcane industries are polygeneration systems producing sugar, ethanol and electricity as main products. The paper developed by Palacios-Bereche et al. [13] compares five different alternatives to improve the energy management and to reduce the environmental impact: increasing electricity production in the cogeneration system, thermal energy integration of process streams, evaluation of second-generation ethanol production, water use in the process, integration with biodiesel production, vinasse disposition aiming at increasing energy production and reducing pollution.

Finally, the next 2 papers related to policy and managerial aspects, dealing with i) the role of subsidies for fostering polygeneration projects, and ii) an interesting application of cooperative games theory for the cost assessment in trigeneration systems were selected.

The paper presented by Hosan et al. [14] analysed the impact of subsidies on energy technology innovation in the 25 highest energy subsidy-providing countries for the period of 2010–2020, employing advanced econometric approaches. The outcomes achieved show that the removal of energy subsidies stimulates technological innovation, which induces the adoption of a renewable-based polygeneration systems, resulting in the reduction of energy poverty and improving social welfare in society. The authors suggest in this paper the need of further innovations in energy subsidy reforms oriented to foster sustainability and technological innovation for polygeneration that may contribute to clean, sustainable, and affordable energy for all.

The last paper selected for this special issue developed by Lozano et al. [15] envisages the problem of cost assessment to the final energy products (heating, cold and electricity) of a trigeneration (multi-product) system. This a very interesting and hot topic because cost allocation in multi-product systems requires special attention, i.e. the way in which allocation is made will affect the prices of the final products and, consequently, the consumers' behaviour. When a polygeneration plant is designed to serve different products, it is possible to achieve a lower total cost. However, if potential consumers are free to consume the energy services produced, the system's management should ensure that every consumer shares the benefit of joint production. Thus, the authors compare in detail 10 different cost assessment methods in multiproduct systems: 5 classical cost assessment methods, 2 classical Thermoeconomic cost assessment methods and 3 cost assessment methods from Cooperative Game Theory. The latter cost assessment methods (Cooperative Game Theory), provide a cost allocation to the final energy products that all consumers benefit in a fair way.

We hope the Readers will find this Special Issue a valuable read and that it could contribute to the very much needed transition towards a sustainable energy production.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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