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Integration of energy systems, circular economy and efficiency measures

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ABSTRACT

With realization that world's resources are limited, a number of initiatives in all global regions emerged to pursue a common goal of sustainable management of energy and material loops. The intensively researched topics are traditionally gathered under the roof of Sustainable Development of Energy, Water and Environmental Systems conferences (SDEWES), which in its 16th edition saw a highly focused and impacting research contributions, tackling the cross-sectoral development and introduction of novel technologies and processes, all devoted to implementation and examination of possible solutions to contribute to Sustainable Development Goals (SDGs). The present paper is gathering and structuring these contributions, enriched with the outcomes of previous SDEWES conferences to enlighten the advances made in the fields of energy harvesting, circular economy and efficient energy use to put into context the role of cleaner chemical engineering. By this, it provides a basis and a guidance for future research on the axis of material-resource-energy nexus which is in the paper identified as an extensively interlinked research area, difficult to be tackled individually and still requiring an important effort to collectively address the cross-sectoral dimension of the challenge.

Introduction

Recent decades have seen unprecedented improvements in the uptake of sustainable practices. These are emerging as a consequence of a well established dedication to maintain at least a current level of living comfort in terms of biodiversity, climate and other environmental aspects. In a society, which is becoming progressively environmentally aware, this serves as a very effective pull factor. On the other hand, self-initiative led to formal establishment of significant push factor, represented through several strategic roadmaps throughout the world which are seamlessly complementing collective society efforts in its strive for sustainability. Worldwide, comprehensive long-term planning practices have been established in the EU through recent deployment of the European Green Deal, which foresees amendments of several related directives and establishment of new ones to even better systematize the pathway towards 2050 environmental neutrality through just transition and decoupling of economic growth from resource use. The actions span from the fields of industry, agriculture, energy, finance to research & innovation and are steered via several action plans. In the light of cleaner chemical engineering, energy use and efficient resource (re)use, the most important are the Circular economy action plan (CEAP) (European Commission, 2020) which sets out a number of initiatives to tackle different material streams and reduction of waste through reduction and recycling. The energy sector is addressed through Renewable energy directive II (RED II) (European Commission, 2021a) by setting out a concept to substantially increase the uptake of renewables in the energy-mix, which is complemented by Energy Efficiency directive (EED) (European Commission, 2021b) which collectively make the net-zero goal by 2050 realistic. Furthermore, a diversification of energy sources is promoted through the latest intervention, delivered through (European Commission, 2022), further elevating the ambitions for energy self-sufficiency in EU. Similarly comprehensive strategies, tailored to regional specifics, needs and development orientations have also been imposed in China through 14th Five year plan (FYP) which plans to drastically reduce the air pollution and sets the most ambitious targets so far on waste management, water pollution and environment restoration and protection, confirming that the strive for sustainability is a world's collective effort. No less ambitious are also the development directions of all world's major regions and long-term goals are almost fully aligned among world's regions. Thus, the development goals provide a fruitful ground for cleaner chemical engineering processes, particularly in relation to upcycling and secondary materials which are becoming pro-

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gressively more important and have, in the recent years, equalized the position importance with energy supply, forming a material-resource-energy nexus.

Background

While industrial and technological development of society was traditionally focused towards improvements in human well-being and towards increase in productivity, recent decades have brought in question the sustainability and the dilemma how to balance the human-oriented development with environment and nature. Many questions opened up since then, some resolved, some remain unanswered, but clear guidelines are regularly being developed how to tackle this challenge. The Conference on Sustainable Development of Energy, Water and Environmental systems (SDEWES) from its first edition onwards consistently and systematically targeted the technical, societal and market advances and delivered a remarkable amount of feasible as well as fully implementable solutions, ready for market deployment. In its 16th edition during 10 - 15 October 2021, the SDEWES conference in Dubrovnik gathered over 600 experts from scientific and professional fields, delivering 675 original contributions, all directly addressing technologies, processes, business models and societal advances, aimed towards balanced development and co-existence of human and the environment. The review process of conveyed research revealed numerous topics with a high potential to impact the future development of energy, water and environmental systems, particularly in the field of sustainable energy harvesting, management and use under the roof of circular economy guidelines. In order to facilitate the dissemination of the most advanced studies in this field and most promising solutions proposed, the selected presented research was extended by the authors, concluded and on this basis invited in several virtual special issues (VSI) in topical journals to aid the scientific community to pin-point the research directions in the years to come.

Dealing with a complex, heterogeneous and highly multi-disciplinary field, present paper is devoted to structuring and systematizing the contributions in several VSI devoted to 15th and 16th SDEWES conference with the aim to gather the developments beyond state of the art and illuminate the scientific progress achieved in the past two years. For previous conference editions, contributions were steered by the VSIs from past SDEWES conferences, which are already consistently analysed and structured in several Editorial and Review papers and form a basis for the present paper as they define key orientations for the current research.

Comprehensive collections from original conferences held in 2020 in Dubrovnik is already available in journal Fuel (Mikulčić and Zhang, 2021), Journalf of Environmental Management (Mikulčić et al., 2021), Applied Energy (Kılkış et al., 2021), Sustainability (Wołosz et al., 2021) and Cleaner engineering and technology (Mikulčić et al., 2022). These are extended with collections from regional, SDEWES South East Europe, Latin America and Asia Pacific conferences, held in 2020 in journals Clean Technologies and Environmental Policy (Pukšec and Duić, 2022), Energy Reports (Buonomano et al., 2022), International Journal of Sustainable Energy Planning and Management (Seixas et al., 2021), International Journal of Hydrogen Energy (Akansu and Kovač, 2022) and Optimization and Engineering (Trafczyński et al., 2021). For the year 2019, contributions from original SDEWES conference were up to now the most comprehensive and are structured in Journal of Applied energy (Vujanović et al., 2021), (Kılkış et al., 2020), Energies (Chu et al., 2020), Energy (Guzović et al., 2022), International Journal of Sustainable Energy Planning and Management (Østergaard et al., 2020), Journal of Environmental Management (Mikulčić et al., 2021), Optimization and Engineering (Mikulčić et al., 2021), Renewable Energy (Østergaard et al., 2020), Thermal Science (Rašković et al., 2020), (Oka and Bakić 2020) and Waste Management & Research: The Journal for a Sustainable Circular Economy (Ragossnig and Schneider, 2019).

The above selected consolidations of research are indicating that the contributions are highly multi-disciplinary, which is a prerequisite to address a complex field of Sustainable Development of Water, Energy and Environmental Systems. At the same time, this interdisciplinarity largely prevents the consolidations of research which would be capable of addressing all interrelations between different sectors. For this purpose, the present paper is aiming to structure and categorize the research presented during the last two years and focuses on the interrelation of the three distinctive categories:

- Integration of energy systems which deals with systemic approach to energy system modelling,
- Towards circular economy through cleaner chemical engineering, encompassing the technologies and processes for upcycling and production of secondary resources,
- Sustainable and efficient energy harvesting and use, which critically reviews the approaches for defossilization of energy sector.

By this it aims to provide an overview of the contributions from the past two SDEWES conferences and enlighten them in the view of energy-circularity-efficiency axis.

Integration of energy systems

Energy systems of the future are a major topic of discussion across the scientific community, among professionals as well as in general public. Although the debate on the exact topology, role of prosumers, management and control is intensifying there seem to be several visions in place which are conditioned by local/regional specifics, technology and resource availability but also by cultural, traditional and societal effects. While envisaged optimized energy systems differ between different researchers, the differences can be considered as minor and the main outline of the future energy systems is consistent across the scientific community – they all rely on extensive sector-coupling to form multi-energy systems, rely on extensive share of renewables and are serving to a highly efficient consumer fleet with which they have multi-lateral relations to form a highly interlinked and decentralized structure.

Given the complexity of envisaged future energy systems, which surpasses the intuitive capabilities for their optimization, the researchers in majority resort to system-level modelling on different scales to deepen the understanding and provide a platform for steering the development. The apparently random nature of energy system behaviour which is caused by overwhelming amount of impacting parameters, paved a way for statistical models for forecasting and simulating energy demand in the long-run (Mauleón, 2022). These are capable of taking into account also factors such as GDP growth, roadmaps, population, human development index and combine it with historical data. For short and mid-term seasonal predictions and planning of intermittency, the gonio formulas with curve fitting can achieve remarkable results which can steer the Supply Side Management (SSM) and propose location, orientation and effective area of photovoltaic panels to provide baseload operation together with wind energy (Mertens, 2022) while also sharing the cable infrastructure.

Modelling of energy systems via physically based models was often employed for case studies with different levels of complexity. Such approach proved suitable to analyse energy systems of different countries and diagnose the barriers for increased uptake of renewables, which are often listed as low feed-in tariffs, low public awareness and large share of legacy conventional energy generation technologies with long service life (Mehta et al., 2022). The results of such models are then often used for roadmap development. Similar approach is used also for local energy systems (LECs), where balancing is done on a smaller scale. Although the complexity is manageable in such cases, the results often reveal that simplified and/or small energy systems usually require at least some form of energy storage and power-sharing strategies to cover the self-consumption (Manso-Burgos et al., 2022). Another case which confirms this idea was presented by Hagos et al. (2022), which consistently demonstrates that battery storage is the most cost-efficient if there is no strong grid availability. When even smaller energy systems are considered (i.e. on a building level), offline monitoring/optimization methods proved to be successful to predict the necessary improvements in energy system (Zini and Carcasci, 2022).

Regardless of these efforts, the research field still requires substantial improvements which will go on for decades as coupling with many other sectors will be necessary. As reported Neumann and Hirschnitz-Garbers (2022), a 100% renewable energy world with zero GHG emissions is apparently feasible, however it is mandatory to take into account the availability of secondary materials for renewable energy generation and ensure value creation in developing countries. In this context, improving recycling is obvious and essential milestone which can provide secondary materials and thus reduce the risk of economic constraints related to depleting high-grade raw material reserves. With increased uptake of renewables, an increasing pressure on rural environment is also expected. While the threat of loss of biodiversity should be the main concern here, increased uptake of wind and solar based technologies will require also a systematic dialogue with general public to increase the public acceptance of new installations. To achieve this, there is a need to move from the current “top-down” approach to a “bottom-up” approach, where the promoted projects enjoy public acceptance, the management processes are transparent and the tangible and intangible benefits are clearly perceived for the area in which the renewables are located (Duarte et al., 2022) .

Towards circular economy through cleaner chemical engineering

The fact that sustainability and energy management go hand-in-hand with the concept of circular economy is now already well established. The research of circular economy is thus often intertwined with other sectors, however, highly focused studies targeting the implementation of circular processes can be considered as a prerequisite for bottom-up approach. They offer a detailed insight into process functioning and form a basis for LCA analyses, optimization of energy flows and integration in the industrial/societal ecosystem. Recent years have seen significant efforts in introduction of bio-based resources in conventional processes for production of drugs (Savic Gajic et al., 2021), dyes (Nambela et al., 2022) and chemicals, thus notably promoting the material cycling loop. An emphasized area of interest is in green solvents, which offer an alternative for petroleum based products in food processing (Prasad et al., 2022) or recovery of secondary raw materials from waste streams as in the case of removal of methylene blue, phosphorous and selenate from paper waste sludge (Manoko et al., 2022). As such processes are notorious for being economically demanding, reduction of energy demand and process complexity is considered as a key enabler. In example, the production of primary magnesium with high efficiency was achieved via a new recycling technique which uses high temperature silicon carbide particles to enhance the heat transfer (Zhang et al., 2022), making the whole process affordable.

The processes for extraction of valuable materials are often also applicable in a reverse fashion – when removing the contaminants from selected material streams. The main driver for this reverse approach originates from the fact that critical materials are often intensively sought to be recovered but they can, in many cases be undesired even in trace amounts due to their toxicity. Such approach is demonstrated in a study by Scheverin et al. (2021), where magnetic-zeolite nanocomposites are used for the removal of fluoride from groundwater to make it fit for human ingestion, confirming that even though the research in some cases seems highly specialized and non-transferrable, a significant potential for synergies and application of novel technologies on several stages of circular economy is possible. In terms of sustainability, the processes of extraction/purification, can also be omitted or at least extensively reduced, if contamination is controlled already at the source. In dispersed applications, such as agriculture, this is challenging and large improvements are necessary in terms of monitoring and control (Piwowar et al., 2021), however, solutions for more concentrated sources are closer to implementation. Typical case is the sustainability assessment of certain processes in steel industry, where contamination with heavy metals and other inorganics is an ongoing issue, but technology alternatives aimed at resource efficiency, such as zinc recovery from spent pickling baths (Arguillarena et al., 2021) could provide the desirable reduction of the environmental impacts associated to primary resource usage and waste treatment.

An alternative approach to the use of waste-extracted materials follows the idea of direct reuse of waste in their raw form. Due to challenges with contamination, cement industry is considered as a highly robust sector and often utilizes highly heterogenous (by composition) fly ashes as a substitute for primary resources. Although this can be considered as a cascade-use of materials and not necessarily a circular approach, the environmental benefits are undisputed and as reported by Maes et al. (2021), there exist notable potential for tailoring the cement production and ash collection processes to accommodate the ash with more loose specifications (also outside standard limits). Taking into account the fact that materials made of concrete typically exhibit lower environmental performance in comparison to ceramic blocks, but offer lower release of polluting gasses (Muneron et al., 2021), the use of waste materials and incorporation of renewable energy in cement production might bring this concept to a tipping point and make it feasible. Nevertheless, such assumptions are to be taken with care, since sustainability in architecture, engineering and construction surpass such isolated effort and extensive material savings can be achieved if sustainable use of resources is pursued in a collective effort, i.e. by following a holistic framework which incorporates also recycling, secondary material use and demolition (Schützenhofer et al., 2022).

Apart from sustainable manufacturing, recovery of valuable material flows and introduction of bio-based and renewable resources in established production processes, an important emphasis is put also on material upcycling with the aim to battle the waste hierarchy idea, established in EU. As reported by Franchina et al. (2021), circular supply chains are the optimal solution to attain green management practices to which the concept of smart cities is invaluable when introducing systemic thinking to tackle the waste generation and management. When waste management is addressed via research of core technologies, the most prominent are the processes dealing with the challenge of waste plastics, which is becoming also an important pollutant. Here, either upcycling of waste plastics to new chemicals seems to be the most in line with circular economy guidelines (Frisa-Rubio et al., 2021), followed by production of fuels, which can still be considered as new products (Tulashie et al., 2022). Nevertheless, the same remains valid as for afore-mentioned extracted inorganic contaminants. Given that majority of pollution with microplastics comes from wastewater and associated garment washing, sustainable practices in textile sector are of utmost importance which can largely resolve the issue of uncontrolled waste plastics emissions, but require careful investigation of consumer behaviour and perception of sustainability as reported by Gomes de Oliveira et al. (2022). However, the recycling rates of waste plastics and selection of final products produced from it seem to be dependent on technical, economic, ecological, organisational, and social dimension which vary across selected cases and still require careful analysis for each case as pointed out by Ragossnig and Schneider (2017).

Sustainable and efficient energy harvesting and use

Owing to an already ongoing energy crisis, the first basis for sustainability is harvesting of renewable and residual energy arising from cascade use of heat. Both concepts are subject of an extensive legislative push, in EU particularly with the Renewable Energy Directive, now on the verge of its 3rd edition (European Commission, 2021a) and Energy Efficiency directive, also on the verge of its renewal (European Commission, 2021b). Already known outlines and drafts are already yielding important contributions in the fields of energy harvesting and waste heat management, efficient energy use in buildings and district heating systems as well as in transport applications.

Energy harvesting and waste heat management

With realization, that potential of waste heat is immense, and currently only approximately 1% of its full technical potential is recovered (Miró et al., 2015), improvements in heat exchangers in various industrial processes are highly important. For this purpose (Wang et al., 2022) investigated flow phenomena in printed circuit heat exchangers for natural gas. In conventional energy sources, thermal deformation of intermediate heat exchangers in nuclear power plants is also a challenge which was addressed by (Xu et al., 2022). By this it is evident that also conventional technologies still require improvements in thermal management. A step forward was then made by Alabrudzinski and Markowski (2022) who investigated a novel concept with a series of reboilers for the purpose of thermal separation in industrial processes which drastically change the approach for thermal management. As phase-change phenomena is highly important in such applications, a study from Cui et al. (2022) extended these effort and provided numerical investigation of more fundamental boiling phenomena in a two-phase closed thermosyphon. Such detailed studies also extend to flat-plate heat pipes (Zhang et al., 2022), which are similarly applicable to numerous energy intensive processes. Thermal management is therefore often a main driver for increasing the energy efficiency, which is also confirmed by Dalle et al. (2022), where Air-gap Membrane Distillation (AGMD) was shown to have an improved energy efficiency in case that appropriate temperature gradient across a hydrophobic membrane is established, which limits heat losses. In more applied investigations, recovery of waste-heat is reported in several utilization scenarios. For drying of sludges (Tańczuk et al., 2016), for recovery via Organic Rankine Cycle (ORC) with novel light-hydrocarbons as a working fluid (Varga and Csaba, 2018) or in terms of systemic integration in stand-alone energy systems on-board ships (Barone et al., 2020).

Beside the efforts to capture the available waste heat, harvesting of renewable energy is a key pillar of sustainability. For this purpose, the research in recent years is strongly focusing on solar energy, geothermal energy, and wind. With realization that land-use change is one of the main drivers for the loss of biodiversity, a number of studies is investigating rooftop systems. (Batista da Silva et al., 2022) resorted to an innovative evaluation of potential, where they data for forecasting of solar energy uptake was gathered from installations of solar water heaters to identify the pace of development. With such decentralized approach as rooftop photovoltaic installation offer, symbiosis with power system must be considered as well. Apparently, when power production is preferred, structures with large number of panels are best to be asymmetrically connected (Ceresuela et al., 2022). Photovoltaics are, however, not the only technology that is being increasingly researched. Alternative, solar to heat technologies are also an important contributor, particularly in industrial heat production. Following the proposal from Panagopoulos et al. (2022) receivers using micro-mirror array can yield a theoretical optical efficiency from 0.7 to 0.9, which fully justifies the direct harvesting of heat from solar energy. Given the expected increased demand for cooling, such technologies are also paving the way for solar-assisted cooling systems based on adsorption, but it seems that the policy and available subsidies do not particularly promote technologies with high optical efficiency, as they focus on the collecting surface size, rather than on energy harvested (Marletta et al., 2022).

Efficient energy use in buildings and district heating systems

Highly important complement to energy harvesting is efficient energy use, as it can, in the first place, reduce the required amount of primary energy produced. As such, it can be considered as a low hanging fruit, since potential is immense. Given the fact that the building sector for its heating amounts up to 40% of EU's final energy use, extensive improvements are possible. The sector-coupling in this field is expected to efficiently contribute towards sustainability and economic performance of energy supply. Therefore an ongoing trend to defossilize district heating networks via integration of waste heat is currently ramping up (Cunha et al., 2022), however this almost always includes extension of the network to incorporate suitable waste heat sources. As seasonal variation of heat supply remains a critical issue, storage technologies based on thermo-chemical technologies (i.e. in salt hydrates) are becoming a promising way to bridge the gap between supply and demand sides when renewables are integrated as a primary energy source (Li et al., 2022). Increasingly important is becoming also the understanding of building stock and its role as a potential storage capacity as presented by Wei and Calautit (2022), which can be, via model based control efficiently exploited. In case of coupling with hourly models for energy assessment (De Luca et al., 2022) accurate prediction of the hourly energy demand for buildings is possible.

Nevertheless, district heating and energy demand prediction can be very efficiently combined with passive technologies, such as night ventilation (Alhindawi and Jimenez-Bescos 2022) and regulation of temperature via thermal mass (Sun et al., 2022) in buildings, which clearly points that traditional methods, often under scrutiny for their apparent inefficiency, can be effective as well if they are properly controlled. Still, energy consumption of household should be assessed also in the light of occupancy behaviour patterns (Zhang and Calautit, 2022) to predict the energy use and thus cope with apparently random nature of energy use. Various models were developed for the purpose of predicting the energy use in buildings, however, seldom are those which extend beyond purely technological aspect and take into account also social dimension to describe user-building interaction within a cultural context, different demographic factors and their relation to heating practices. These can severely impact the results of purely technology oriented models up to 43% (Piselli et al., 2022). The improvements in prediction-capability are therefore still possible, but they have to be addressed multi-disciplinary and have to take into account also future climate change, which predicts significant shift from heating to cooling, even up to 20% in the current century (Guarino et al., 2022) which will sooner or later require a moderate adjustment of the research focus.

Given the importance of the energy efficiency in buildings, the advances towards energy-efficient homes is well represented in the community. The efforts do not stop at increasing the energy efficiency, but extend also towards deployment of nearly zero or zero energy buildings by taking into account both indoor comfort conditions and efficient management and control (Magrini, Marenco and Bodrato, 2022) as well as building site analyses where particularly the presence of underground water can increase the heat losses from 24% - 54% (James et al., 2021). This type of analyses often reveal that selection of technologies and energy management is not intuitive, but requires careful optimization as in the case of nearly-zero-exergy greenhouse or nearly-zero carbon greenhouses which are highly dependent on type of air conditioning and energy source used (Kilkis, 2022). Results show that the exergy approach provides crucial insight for the design of labyrinth-type ground-to-air heat exchangers and sets new constraints about limited environmental benefits which clearly links the research to waste heat management. In more component-oriented research, a lot of emphasis is still placed on glazing (Moreno et al., 2022) where transparency and insulation seems to present a challenging compromise, however roofs are almost exclusively optimized for insulation performance in terms of heating and cooling and require a new set of indicators how to evaluate their performance in broader terms. In study by Lodi et al. (2022) a solar transmittance factor was introduced to aid with relevant metrics for this purpose. Another effort towards new metrics for HVAC systems and their capability to meet contemporary loads was introduced for polyvalent heat pumps by Crespi et al. (2022).

With a wide selection of new technologies, the questions are arising whether they should be implemented only in new buildings or if they are also suitable for retrofitting. It turns out that cost-optimal methodologies for designing the retrofit should always incorporate life cycle cost analysis and evaluation of potential saving based on optimized control of building energy systems, since non-optimized mix of implemented technologies and control strategies can severely impact the return on investment and by this also market attractiveness (Heracleous et al., 2022).

Clean transportation

Based on the how different sectors are cross-linked, and owing to the fact that more than 30% of final energy consumption in EU is used for transport applications, a notable amount of research is devoted to this topic, however it is seldom investigated as a stand-alone challenge and is rather combined and interwoven with upper sectors of environmental systems and circular economy. Topic et al. (2021) are thus assessing the ship emissions in coastal waters with spatial projections of routes and taking into account propulsion system data to investigate the interaction with environmental systems. In land-based transport, optimization of transportation within cites (i.e. Vienna) is investigated via methodological approach for modelling the impact of different policies on mobility and embedded greenhouse gas emissions from vehicles up to 2050 (Siebenhofer et al., 2022). With a goal to defossilize the transportation, alternative energy carriers are also discussed, either waste cooking oils for use in conventional propulsion technologies (Adhikesavan et al., 2022) or biodiesels upgraded with alcohols (Tosun and Aydin, 2022). These were previously also analysed within highly flexible propulsion systems with either dual-fuel (Rašić et al., 2017) or even triple-fuel concepts (Oprešnik et al., 2012). These concepts are often combined with production of alternative energy carriers (bioethanol) from wastepaper (Sharma et al., 2022). When using conventional technologies, based on internal combustion engines, stringent emission limits will have to be met after the Euro 7 Emission Standard implementation in the close future. These call for detailed analyses of micropollutants and the effectiveness of different catalytic metals, which were thoroughly reviewed by Pacura et al. (2022). Among energy carriers, particularly supported by recent EU package RePower EU and Biomethane action plan (European Commission 2022), biogas is also increasingly investigated in terms of economic and environmental impact (Fedeli and Manenti, 2022). In more ambitious cases, shift of Urban public transport from conventional to electric busses and different mixes of bio-fuels are researched (Leichter et al., 2022), which again offer the possibility to combined them with different powertrain technologies (Oprešnik et al., 2018) to maximize their economic and environmental performance. With rail transport becoming increasingly accepted as one of the most environmentally friendly solutions, understanding a full lifecycle and energy demand for building stock in rail infrastructure is also highly important to fully understand the environmental impact (Barone et al., 2022). As in previous cases, the sector coupling has to be taken into account also when designing future transportation modes. According to a recent study Abid et al. (2022), where TransportPLAN software is used, optimized planning of transportation together with urban development can importantly contribute towards the uptake of sustainable mobility solutions and reduce the energy consumption for transport by 20% by 2050.

Conclusions

The conveyed research clearly points out substantial co-dependence of several different fields. While some solutions seem to be effective already if they are implemented on their own, the vast majority of proposed improvements are impacting many sectors and have to be treated collectively. Based on the focus and justification of the selected research, published in the past two editions of SDEWES conferences and related to energy harvesting, circular practices and efficient energy use, it can be concluded that the most promising and also most challenging topics are covering the optimization of energy systems via virtual approach and with included considerations of societal impacts, secondly, the introduction of circular thinking into waste heat management by upcycling the waste heat, together with extensive investigations directed towards upcycling of waste streams of man-made polymers and finally also with efficient energy use in buildings and transport, which sum up to the majority of energy use. Withing this focus, cleaner chemical engineering seems to be an integral part of sustainable development. It takes on the role of the connecting tissue which enables implementation of circular economy guidelines and production of secondary materials, which are becoming increasingly important not only to drive the energy transition, but to contribute towards highly sought material efficiency as well. With increased uptake of new technologies, requiring either critical raw materials or secondary materials of sufficient quality, the research in cleaner chemical engineering will have to be appropriately directed to support sustainable transformation. From the current research opus it can be extracted that the key topics will cover either new methods for extraction of inorganics, either for recovery or de-contamination purposes and also upcycling of organic materials, bio-based and artificial, through chemical recycling processes. However, these technologies should be carefully implemented in order not to become a victim of their own success, they should always follow the waste hierarchy and give way to waste reduction and reuse methods, accompanied by changes in consumer behaviour and new business models. These will not only contribute to sustainable practices in the material loop, but will greatly aid to reduction of energy use and hence also reduce the necessity for implementation of sustainable energy harvesting technologies, which are currently known to be demanding financially as well as in material resource terms.

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.

Data Availability

No data was used for the research described in the article.

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