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Silver Jubilee of PRES Conferences: Contributions to Process Integration Towards Sustainability

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The paper provides an updated overview of the main achievements and ideas presented at the most recent PRES conferences and in the fields which have been covered by them. The conference history now reached a quarter of the century – from 1998 to 2022. The PRES conferences have become one of the main vehicles for spreading Process Integration (PI) into various research directions and fields of possible implementation.
The PRES went successfully during the last period challenged by COVID-19 pandemics. Not all conferences managed to adapt well. However, PRES successfully implemented the hybrid mode and learned how to use it efficiently for enlarging the number of speakers as well as the audience while still keeping very intensive and beneficial cross-fertilisation and networking. Some experiences have been shared in this paper. The hybrid mode helped successfully intensify the research efforts on the research challenge, which remained as a consequence of the COVID-19 pandemics – an increased amount of waste and during the life and economy recovery also increasing environmental footprints.
This short overview includes

(i) Process Integration with Pinch Analysis
(ii) Process Integration with another approach
(iii) Development of heat exchanger systems for Process Integration
(iv) Other extensions of Process Integration for wider Process Systems Engineering and recently
(v) Circular economy
(vi) Environmental footprints and nexuses and just
(vii) COVID-19 pandemics energy and environmental consequences and recovery.

This paper presents an attempt to demonstrate and make suggestions for the future growth of the Process Integration branching out during the next years.

1. Introduction

The history and achievements of PRES conferences have been reaching Silver Jubilee - 25 years. The leading topic from the very beginning has been Heat Integration, which has developed into Process Integration with many new offsprings for sustainability and circular economy. It is continuously developed to follow the progressive needed of the developing society and environmentally friendly production. It has become a good tradition to start the PRES conference dedicated volume with an overview of the last period. The series started with an overview of Friedler (2009) and the further elaborated analysis (Friedler, 2010) and continued with teamwork in 2017. Klemeš et al. (2017) have analysed the twenty years of PRES, Klemeš et al. (2021a) twenty-

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four years, and this PRES'22 continues. The leading idea of this overview is, to sum up, remind and further develop the knowledge and contribute to its sharing and cross-fertilisation amongst researchers worldwide.

2. Contributions – previous achievements and PRES'21

The comprehensive reviews have been regularly presented – for instance, in (Klemeš et al., 2018a) and other books such as (Klemeš et al., 2014) with a more recent second edition (Klemeš et al., 2018b). A special place has a comprehensive Handbook of Process Integration - Klemeš et al. (2013), which has been just published in an updated second edition Klemeš et al. (2022).

2.1 Process Integration with Pinch Analysis

There have been several lines of development using Pinch Analysis in the past year. Bandyopadhyay (2021) reviewed the incorporation of uncertainties into Pinch Analysis. The review established that there are two main types of uncertainties – probabilistic (stemming from inherent variability of the properties) and epistemic (stemming from lack of precise information). The analysis pointed to the connection of Pinch Analysis to Chance-Constrained Optimisation for probabilistic uncertainties, while for the epistemic case, interval-based and fuzzy models were found more appropriate.

A Carbon Emission Pinch Analysis case study has been presented by Saleem et al. (2021). The authors performed the study in an attempt to support the GHG emission reduction policy of Malaysia for the coming decade. A methodological development - Organic Waste Valorisation Pinch Analysis has been presented at PRES'21 (Chee et al., 2021), which linked the carbon-nitrogen load and the overall waste flowrate for the case of waste reuse in the context of symbiosis networks for the valorisation of organic waste streams to supply various bioprocess demands in a given locality. The method allows targeting the maximum amount of waste valorisation and the minimum external resource supply, also identifying the Pinch Points that limit the reuse.

Chin et al. (2021b) have developed a prototype concept for the inclusion of water mains representations in the targeting of water reuse networks, where the water reuse takes place via several water mains, as opposed to peer-to-peer network organisation. They have shown the basic incorporation of the water mains plots into the charts with Source and Sink Composite Curves and their role in the identification of the Water Recovery Pinch. The idea was later fully developed into a comprehensive targeting method by Chin et al. (2021a), adding a complete procedure for source-sink allocation and handling of multiple water headers.

Markowski et al. (2021) have applied Heat Integration Pinch Analysis for targeting and retrofitting the design of energy recovery networks utilising the heat in steam condensates. Both condensation and sub-cooling segments of steam utility streams have been included in the targeting and the optimisation models for industrial heat recovery networks. They were able to identify measures resulting in about 11 % hot utility savings and extra power generation without additional fuel intake. Inayat et al. (2021) have applied Pinch Analysis to the domain of the cast-iron industry. The case study has identified a specific process unit with hot streams coming from furnace exhausts and cold streams from the underlying process, as well as an absorption chiller heating demand. The authors performed targeting and HEN design achieving the targets resulting in 80 % heat recovery. An extension of Total Site Heat Integration to the utilisation of geothermal heat has been presented by Wang et al. (2021a), illustrating the potential to save up to 70 % utility steam in an industrial context.

Further natural development of the Total Site principle towards "Total EcoSite Integration" has been presented by Fan et al. (2021c). That work has introduced several conceptual innovations: (a) semantic grouping of symbiosis actors into industrial and urban clusters; (b) explicit consideration of waste valorisation; (c) footprint assessment. Yet another extension of Pinch Analysis – combining several known methods into a framework, has been formulated by Ch'ng et al. (2021) – WAste Management Pinch Analysis (WAMPA), Total Site Heat Integration (TSHI), cogeneration targeting and optimisation, Power Pinch Analysis (PoPA), GHG-emission constrained site planning, CO_2 utilisation, site water minimisation. The authors reported achieving the reduction of more than 95 % of landfills, 49 % of GHG emissions, 45 % of steam generation, as well as the elimination of the need for an external supply of water and power.

2.2 Process Integration with another approach

Process Integration could be conducted with another approach than the Pinch Analysis. Mathematical optimisation is among the common approach as performed by Emtir and Elbabour (2021) for Heat Integration of distillation system with the background processes, using minimum total annual cost as the objective function. A 41 % of TAC saving can be achieved by the integrated design (Emtir and Elbabour, 2021). Potrč et al. (2021) developed a dynamic mixed-integer linear programming model to optimise all sustainability pillars simultaneously for an integrated energy system for the EU. Heat pumps and the inclusion of biomass combined heat and power systems are highlighted as the key solutions to meet renewable heat demand. Fan et al. (2021b) applied both the mathematical optimisation method and extended Pinch Analysis based on the clustering concept for biomass integration. The method is demonstrated through a case study for Tomsk Region, and a 40 % lower GHG footprint is suggested compared to the biomass waste limiting for local utilisation. Other than Energy Integration, multi-period resource integration in carbon dioxide is performed by Abraham et al. (2021) using a mixed-integer linear programming model. A data-driven Artificial Intelligent in Process Integration has been proposed by Kong et al. (2021), capable of capturing the temporal aspects, uncertainties and multi-gent or multi-objective.

2.3 Development of heat exchanger systems for Process Integration

The importance of improvement of energy recovery and reduction of emissions has aroused great attention considering the environmental burden of our homeland and the happiness of human beings. A recent project about Enhancement and Energy Optimised Integration of Heat Exchangers in Petrochemical Industry for Waste Heat Utilisation has been successfully finalised by SPIL from the Brno University of Technology and Xi'an Jiaotong University (Zeng et al., 2021). Innovations have been developed for energy recovery methods, ways of using low-grade heat, and waste heat utilisation approaches and tools.

The integration of different types of heat exchangers in the HEN is a way to increase the efficiency of energy utilisation (Wang et al., 2020). With the fast development of Plate Heat Exchanger (PHE), a new heat recovery method should be developed to integrate this type of heat exchanger with traditionally used types such as shell-and-tube heat exchangers. Arsenyeva et al. (2021) developed a P-graph-based HEN synthesis approach to consider different types of heat exchangers for both new HEN synthesis and existing HEN retrofit. Wang et al. (2021b) analysed the features of various types of heat exchangers as well as the latest developments of methods for HEN synthesis and retrofit. Then a new optimisation framework that could consider the material type and heat exchanger type selection was proposed. The framework has two stages, (i) diagnosis and pre-selection and (ii) optimisation via evolutionary algorithm. The framework has the potential to be widened by extending its heat exchanger and material database.

The P-graph framework is extended to the area of heat exchanger systems for Process Integration. The main idea proposed by Orosz et al. (2022) was to first generate n-best HENs using P-graph according to the HEN structural constraints. Then a heuristic framework was proposed to optimise the parameters in the HEN generation algorithm. The method also enabled the changing of parameters according to the engineering required to generate new solution sets.

Since it was first proposed in 2015, SRTGD has been extended by many scholars recently due to its benefits for network analysis and targeting. Li et al. (2021) proposed an extended SRTGD to consider the temperature effectiveness of each heat exchanger. The thermal efficiency of the individual heat exchanger is connected with the HEN retrofit process. Through this tool, the HEN can be retrofit without topology modification. Wang et al. (2021c) considered the prohibited and restricted matches in the HEN synthesis with the development of an extended SRTGD. The trade-off between risk cost and utility saving was compared, and the comparison result was shown through a Benefit Diagram. The proposed framework contributed 2.5 % economic benefit to a studied case compared to the solution that simply removed prohibited matches after the synthesis.

Another trend for heat exchanger systems development is to simultaneously consider the HEN synthesis or retrofit with the detailed heat exchanger design. Wang et al. (2022a) integrated a detailed plate heat exchanger design with the HEN retrofit by developing an advanced Grid Diagram based framework. The results showed that brazed plate heat exchangers save 6.6 % of the investment cost compared with the solution in just shell-and-tube and double pipe heat exchangers were implemented.

There are some cases in practical operations where the parameters of the processes change. These uncertain parameters connect to the cost and profit and should be well handled in the Process Integration of heat exchanger systems. Sudhanshu et al. (2021) integrated Pinch Analysis and robust optimisation to consider the uncertainty from the inlet temperatures of streams. Zirngast et al. (2021) considered the uncertain parameters in the HEN synthesis and proposed an improved iterative algorithm to solve this issue. A smaller two-scenario MINLP model and a one-scenario NLP model were iteratively solved to ensure that the number of uncertain parameters is not related to the size of the problem. The correction factors for the second-stage variables were introduced, and they contributed to reducing the total annualised cost by 7.6 %. For HENs with multiperiod operations, Isafiade and Short (2021) developed a method based on the Stream Temperature Versus Enthalpy Plot (STEP) and Heat Allocation and Targeting (HEAT) plot, the solution of a case solved by this method underestimated the representative heat exchanger areas by 12.3 %.

An industrial application of using the Heat Integration method for retrofitting an existing natural gas purification process was presented by Zhang et al. (2021). In that work, both the HEN and operating variables for towers were optimised by a two-stage iterative method. The method had a PSO as an outer loop to optimise the tower operating variables and an SRTGD-based model solving algorithm as the inner loop for optimising the HEN. The results showed a 41.5 % reduction in the total energy consumption of the studied process after the retrofit.

Gil et al. (2021) considered the historical data of energy prices in a retrofit design of a crude oil distillation unit. The economic benefits of several retrofit options were calculated under different energy prices.

2.4 Other extensions of Process Integration for wider Process Systems Engineering

Food security has been identified as a key factor in ensuring the uninterrupted supply of food to a highly interactive world stressed by climate change effects, population growth in several regions, and difficulty in containing a local level incident such spread of global diseases (Hammad and Falchetta, 2022). Decisions in the distribution of agricultural land use could have an enormous impact on strengthening the productivity levels and simultaneously reducing environmental pressure. To this end, Sadenova et al. (2021) combined soil content information through satellite imaging, vegetation coverage overview, meteorological data, and correlations on crop yield through the incorporation of historical data to develop accurate predictive mathematical models for crop yields. The models can be utilised in decisions for efficient land distribution and is an excellent example of big data analysis for sustainable agriculture.

The further incorporation of the impact of agricultural practices and supply chain issues on water and energy requirements as well as released emissions create a unique paradigm for process systems engineering methods and approaches. In addition, food consumption habit shifts can create great potential in environmental indicators, such as food self-sufficiency, GHG reduction, and nitrogen input, as suggested by Drofenik et al. (2022) through optimised scenarios. Blockchain technology has been utilised for the resiliency and monitoring of the state of agricultural supply chains enabling trust and transparency among those involved in the entire chain and increasing the ability of the system to cope with abrupt and large magnitude and impact disruptions, e.g. COVID-19 pandemic (Khan et al., 2022).

Energy networks and systems with a large penetration of renewable energy sources have increased their complexity in structure and their degree of interaction. The number of producers and consumers for various forms of energy in such a system is very large and therefore monitoring the state of the network's performance and its resiliency to systematic and random shocks of different intensity and magnitude is very hard to estimate (Tsao et al., 2021). Energy storage is very important in ensuring the uninterrupted supply of energy, but the selection of energy storage technology and the physical allocation of the storage facility are important in forming the response time of the energy network.

Cormos et al. (2021) considered the design and operation of a thermos-chemical energy system in conjunction with CO_2 capture through a calcium looping cycle with a significant reduction in capture, electricity generation and investment costs. Ortenero and Tan (2021) demonstrated a systematic evaluation procedure for energy storage technologies with lithium-ion batteries providing the most favourable solution in terms of cycle efficiency and volumetric power density. Kyriakides et al. (2021) investigated the optimal scheduling of the environmentally benign waste heat absorption refrigeration with vapour recompression units in district cooling networks. The proposed approach incorporated the network dynamics in order to determine the response of the system to changes in the demand load. Blockchain technology is emerging as a new approach to monitoring and identifying bottlenecks in renewable energy systems (Gawusu et al., 2022). The decentralised nature of blockchain technology enables efficient monitoring and data management which are essential elements in the operational readiness of renewable energy systems to respond to perpetual changes and disrupting events.

The adoption of new technological advances in manufacturing, processing of goods, use of resources, and the mitigation measures against climate change and environmental impact faces an additional hurdle which is associated with social-phycological factors. Such factors connect each individual's values, perceptions, and behaviour relative to technological and environmental concerns to the selection of the most appropriate technological solution and the formation of a suitable policy. COVID-19 vaccine campaign was absolutely successful in the scientific approach leading to the discovery of the vaccine, the process innovation for the quick deployment of massive production units, and the efficient distribution of the vaccine doses to almost every corner of the world.

However, the main failure was focused on the generally hesitant social acceptance by people. Such an example underlines the potential of studying novel process integration solutions in conjunction with existing social misconceptions (Granco et al., 2019). Wijayasekera et al. (2021) provided a thorough review of the evaluation of waste-to-hydrogen technologies based on socio-environmental criteria as well. In another attempt, Fan et al. (2021a) included economic indicators and circular material used to build a predictive model for waste generation. Yang et al. (2020) explored social and economic indicators in the consumption and trade of goods and services patterns in the Asia-Pacific region and identified key weaknesses associated with environmental education and consciousness that hinder quicker progress towards sustainability.

2.5 Circular economy

Since the last review presented by Klemeš et al. (2021c), there have been numerous developments on the topic of Circular Economy (CE), and many have been contributed by the PRES conference. Searching Google

Scholar (2022) for the term “circular economy” produces an extensive list indicating 198,000 results. Limiting the search to publications from 2021 and sooner produces a list of 21,700 results (10.96 %). This shows an accelerating trend of research on the topic overall. There have been key contributions by PRES conferences (about 75) and the related special issues. The key contributions of Process Integration and PRES to Circular Economy research until 2019 are reviewed and analysed in (Klemeš et al., 2019) – emphasising energy saving and the use of renewable energy in a clear hierarchy of energy-saving integration and renewable supply. The review identified the need to embed Life Cycle Analysis (LCA) into the research on energy optimisation and Circular Economy. That strategy has been followed partly by Ch’ng et al. (2021), where the Total Site planning for minimising resource intake was investigated – achieving a simultaneous reduction of energy, water, waste and GHG emissions.

2.5.1. PRES’21 contributions

Ngan et al. (2021) have directly followed upon the idea for embedding LCA into Circular Economy research, providing an LCA framework CE implementations and illustrating the concept on the example of Malaysian palm oil processing and a similar team of authors reasoned in (Lim et al., 2021) the need to integrate smart technologies for achieving optimal results. That has been complemented by a case study (Dessie et al., 2021) on recycling spent mushroom substrate.

The importance of plastics recycling has been recognised even more as a result of the COVID-19 measures, and this has been properly reflected in the PRES’21 conference research – including a base investigation of the processes of implementing plastics recycling (Tocháček et al., 2021), a systematic method for the classification of plastic materials (Chin et al., 2021c) and a prototype Pinch-based procedure for targeting the recycling of plastics (Varbanov et al., 2021a) That has been further followed by the complete development of the method for Plastic Pinch Analysis (Chin et al., 2022) – linking all key stages of material classification, identification of the key sources and sinks for a symbiosis network and targeting the optimal material recycling. The application of LCA variants to the chemical recycling of plastics has been discussed by Zhao and You (2021), demonstrating how to reduce the environmental impacts of the process by at least 17 %.

Further important contributions have concerned the method for integrating composting and biochar use (Bong et al., 2021) for biomass waste treatment. The concept allowed significant prevention of carbon loss for achieving more sustainable soil management. Bubpha and Siemanond (2021) have discussed the integral optimisation of crude oil distillation and heat recovery via Heat Exchanger Networks, demonstrating the economically attractive achievement of up to 65 % of CO_2 emission reduction. Further, a trend-setting investigation has been the multiperiod optimisation of CO_2 utilisation networks by Abraham et al. (2021), evaluating the technical and economic feasibility of obtaining chemicals such as urea, methanol, and ammonia. The optimisation study shows the technical feasibility and provides the basis for evaluating the emission saving and economic potential of the proposed processes. Worth mentioning is also an extension of the emission-constrained Pinch Analysis (Aviso et al., 2021), extending the model to an input-output model and using the land footprint as the criterion for optimising the network. The study demonstrated the potential of GHG emission reduction from the optimisation of product trading networks as well as the idea of using hydrometallurgical methods (Shoshay et al., 2021) for the extraction and recycling of valuable metals from electronic waste, achieving extraction rates of 51 % for silver and 89 % for gold, also pointing to the ways of improving these rates.

2.5.2. PRES Special Issues and other related publications

The journal Virtual Special Issues (VSI), inspired and managed by members of the PRES International Scientific Committee, has also made notable contributions. The VSI of the Journal of Cleaner Production from PRES’19 (Varbanov et al., 2021b) has been the one to put the CE topic at the front of the research for energy saving and pollution reduction. The paper provides a systematic analysis of the PRES and other contributions within the context of the global material cycles of the Earth – water, carbon, oxygen, nitrogen, sulphur, phosphorus, and chlorine. The overview has shown the need for novel modelling concepts – such as viewing the business systems as integral networks instead of supply chains, which natively account for the natural material cycles as well as for the active recycling by the business networks.

The PRES’19 VSI of Renewable and Sustainable Energy Reviews includes a contribution (Deng et al., 2020) on biomass valorisation with multiple recycle flows – including energy recovery and optimisation of the energy yield while minimising the waste flow. Fan et al. (2020b) have analysed the roles of energy management and recovery tools in the context of the overall hierarchy of circularity and sustainability practices known as the “9R”. A key enabler discussed is energy storage. The PRES’20 VSI of Renewable and Sustainable Energy Reviews (Wang et al., 2022b) has considered CE directly by analysing the energy supply, waste-to-energy and renewable energy sources that both stimulate the circular pattern of process design on the demand side and reduce the environmental footprints on the supply side.

A key prototyping and network optimisation tool for Circular Economy has been P-graph (Friedler et al., 2022), whose link to Process Integration and Circular Economy contributions have been apparent and well documented – e.g. for cogeneration optimisation (Tay et al., 2020) or municipal waste handling implementing Circular Economy (Fan et al., 2020a).

2.5.3. Cutting edge – PRES'22 submissions

The current conference venue – PRES'22, has accepted quite a few presentations explicitly targeting CE or its implementation components. Varbanov et al. (2022) analyse the targets for minimising energy demands for plastics management, while Fan et al. (2022) emphasise the LCA of the environmental footprints from plastics management. The synthesis of plastics recycling networks (Tan et al., 2022) is another promising investigation. Further important investigations include those on Chemical Looping Combustion using energy storage (Cormos et al., 2022), the integration of waste biomass into chemical production (Yeo et al., 2022) for displacing petroleum raw materials, valorisation of waste from oil refineries (Niewiadomski et al., 2022), solvent recovery and reuse in biorefineries (Lehr et al., 2022), and the application of Process Integration thinking to the management of building renovation waste (Yu et al., 2022).

2.6 Environmental footprints and nexuses

With climate change and other environmental burdens, there is an increased interest in measuring and mitigating negative environmental impacts. However, the question is how to measure and reduce environmental burdens. The researchers, organisations, policy-makers, and others are putting forth efforts to develop concepts and metrics measuring environmental sustainability. Among those concepts and metrics, environmental footprints and nexus ideas have been drawing increasing popularity and play an ever-increasing role in sustainability evaluation and research. Over the past years, footprints and relevant nexus ideas have been widely used as environmental protection indicators almost exclusively.

Challenges of high energy efficiency, water saving, low-carbon emissions, waste management and food saving have been considerable pressures on both regional and global sustainable development, especially when facing the challenges of reducing environmental footprints. Environmental footprints and nexuses related topics have been successfully presented via the PRES conferences, and sets of impressive outcomes have been obtained by the PRES team. Since the very successful article developed by Čuček et al. (2012) that reviewed the environmental footprint analysis tools for monitoring impacts on sustainability, the environmental footprints relevant studies from the PRES team have been widely extended, including water footprint assessment (Jia et al., 2021), energy footprint analysis (Klemeš et al., 2020b), carbon emissions footprint quantification (Fan et al., 2018), waste footprint exploration (Klemeš et al., 2021a), and Carbon-Energy-Water (CEW) nexus discussions (Wang et al., 2021d).

It has been increasingly crucial to identify each environmental footprint from macro to micro scales, especially under the Sustainable Develop Goals (SDGs) and the Paris Agreement (Wang et al., 2022c). However, different kinds of environmental footprints are usually entwined in industrial processes, environmental processes and ecological processes, which inspires the idea of nexus among different environmental elements. Wang et al. (2021d) revealed the unsustainable imbalances and inequities in embodied CEW flows across the EU27, identifying the embodied carbon footprints, energy footprints and water footprints of different regions. The EU27 countries exert significant influence on the global patterns of the CEW nexus. The regional embodied Carbon-Energy-Water efficiency of china was identified by Wang et al. (2021e), including the embodied CEW coefficients, the total amount of embodied CEW and embodied amount of CEW per capita of 31 provinces/regions in China. These studies target the contribution to understanding the regional CEW efficiency performance, highlighting the spots and economies that deserve the uppermost attention for mitigating the environmental footprints. However, very few studies, to date, have been conducted to comprehensively review the assessment approaches, challenges and trends for CEW nexus analysis. To narrow the research gap, Wang et al. (2021f) review the assessment methods, challenges of CEW network management and ways to go in the future. Eight different kinds of tools were reviewed and analysed, as well as their advantages and drawback. Five future directions of the CEW nexus study were proposed, providing a better understanding of the CEW nexus and presenting a set of approaches for CEW nexus assessment.

Tan et al. (2021) explored the sustainable food-energy-water nexus optimised palm oil-based complex by incorporating the Shapley-Shubik index and debottlenecking framework, revealing that the palm oil mill effluent elimination reduces 97 % of GHG emission for debottlenecked palm oil mill. The planning of the power generation sector in the United Arab Emirates from the climate-energy-water nexus perspective was as well (Lim et al., 2018). In their study, the scope of analysis covers CO_2 emissions, energy return on energy investment, and water footprint, revealing the 50 % clean energy supply options for the 2050 Energy Plan of the United Arab Emirates. The optimisation of the energy-water-waste nexus at the district level was explored by Misrol et al. (2021) by using a techno-economic approach. A mathematical model of energy-water-waste nexus is developed in the above study, showing that 3.2 MW of renewable power and waste heat are able to be recovered in the case study, and 66 % of freshwater reduction plus revenue generation were from the recovered resources.

Many efforts have been made by the PRES team as well to analyse and mitigate the COVID-19 pandemic's relevant environmental footprints. Klemeš et al. (2020a) quantified the energy and environmental footprints of COVID-19 fighting measures at the early stage, including personal protection equipment, disinfection and supply chains. The outcomes emphasised that diversifying solutions to achieve the needed objective is a vital strategy to improve susceptibility and provide higher flexibility in minimising the environmental footprints. They also explored the way of minimising the present and future plastic waste and energy footprints related to COVID-19, considering and reducing environmental, including GHG footprints (Klemeš et al., 2020a). The concept of Plastic Waste Footprint was proposed by them for capturing the environmental footprint of a plastic product throughout its entire life cycle (Klemeš et al., 2020b), proposing six future research directions to mitigate the potential impacts of the pandemic on waste management systems.

Environmental footprints and nexus topics are significant parts of PRES team research. Much more work and contributions than mentioned above have been made by the PRES team. One of the core targets of PRES is to improve the efficiency and sustainability of industrial and regional systems, reducing the environmental footprints (Wang et al., 2022b). More promising works within the scope of the PRES team will be delivered at the coming PRES conferences.

2.7 COVID-19 pandemics energy and environmental consequences and recovery.

COVID-19 pandemic influences Process Integration towards sustainability. Several works related to the COVID-19 impacts were presented in 2021, under the PRES contributions, as summarised in Klemeš et al. (2021a). One of the direct impacts of the COVID-19 pandemic is on the teaching adaption and delivery module, as presented by Aviso et al. (2022). The remote learning platform is the solution during the lockdown implementation response to COVID-19. It reshapes the original system (e.g. education system, business system) and lifestyle, accelerating the growth of digitalisation. Digitalisation could be an advanced development; however, the exact effectiveness and energy consumption have to be assessed (Jiang et al., 2021). Zafeiriou et al. (2022) highlight the importance of creating safer and more sustainable energy systems for the future unexpected or extreme situations like a lockdown. The short term reduction of energy consumption due to the pandemic (Russo et al., 2021) and changes in air quality and water pollution (Siddique et al., 2021) are observed.

Klemeš et al. (2021b), in contrast, underline the energy and environmental impacts of vaccination during the second stage of COVID-19. The environmental performance of the vaccination process is not optimised due to the urgency of battling the pandemic. A sustainable supply chain model that responds to an emergency arrangement is suggested as an important research direction (Klemeš et al., 2021a). Mofijur et al. (2021) suggest that delays in energy projects are expected and would create uncertainty in the coming years. Hoang et al. (2021) agreed on the significant effect of the economic shock on the clean energy transformation, as also highlighted by Hemrit and Benlagha (2021), but the authors also highlighted that pandemics emphasise the potential role of renewable energy during various lockdown episode. The potential opportunities for an energy transition from the perspectives of price competitiveness, policy implementation efficiency, and renewable energy strengths by the pandemic are discussed by Tian et al. (2021). Su and Urban (2021) also suggested that the COVID pandemic is a new opportunity to introduce circular economy measures. The roles of innovative smart energy systems and novel energy materials in improving the energy system efficiency and sustainability are highlighted by Chong et al. (2022).

3. Discussion

When the achievements of PRES conferences have been discussed on various fora, the outcome has been mostly positive. The conference managed, as a result of the pandemic's difficult period, to transform itself into a new hybrid format which is very likely to stay with for the future (Tao et al., 2021), combining the advantages of both face2face and virtual participation, presentation and research discussion. Very positive was that, unlike some other conferences, managed to successfully continue during the hard lockdown periods. This has been possible due to a specifically developed editorial and presentation platform used by several collaborating conferences, mainly PRES and SDEWES (COMET, 2022).

4. Conclusions

To conclude, after the first twenty-five years of PRES conferences: The venue was firmly established for the competitive conference market after the first years became so sizable that it has been organised as an individual

conference with 500+ contributions. In research and scientific terms, it has been providing leading ideas for future development in the field. A very important part becomes, besides the traditional Chemical Engineering transaction, also Virtual Special Issues (VSI) of more than five scientific journals, which are proving the publication opportunities for the authors at various stages of their research development. They take into consideration that journals with the IF close and even above 10 have a high rejection rate and are difficult to succeed for junior researchers.
The authors of this overview have been expressing their optimistic attitude and dedication for the future years of PRES conferences to serve the coming and future research generations.

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