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Review Paper

ACHIEVEMENTS AND PERSPECTIVES OF PROCESS INTEGRATION IN CIS COUNTRIES

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Abstract

Due to the rapid growth in the world population, there has been an increase in energy consumption globally. The problem of efficient energy use becomes more relevant and stimulates research and development of new energy and resource-saving technologies. This task is becoming more complicated when the other factors are accounted for, resulting in multiple-factor trade-offs, such as the water-energy-food nexus. This paper highlights the main points for the development of Process Integration in the Commonwealth of Independent States (CIS) countries. It shows the main achievements in the field to date and demonstrates the scientific schools that are working on these problems. A comprehensive review of modern approaches and methods, which are now being developed or have been recently developed, was done. It shows a research gap in Process Integration in CIS and other leading countries. It demonstrates the significant research potential as well as practical applications. The main challenges in process systems engineering and for the sustainable development of industrial energy systems are also discussed. Industry digital transformation, energy transition, circular economy, and stronger energy and water integration are pointed out as priorities in analysis, design, and retrofit of society in the future. A state-of-the-art review in the area of integration of continuous and batch processes, mass integration technologies, and process intensification is presented to show the variety of existing approaches. The necessity of Process Integration development in the CIS is shown to be a necessary condition for building a more sustainable society and a resource-efficient economy.

Keywords: Process Integration and Intensification, Energy and Resource Saving, Process Industry, Emissions Reduction, Sustainability.

1. Introduction

The rapid growth of the world population requires a considerable amount of natural resources. The utilisation of these resources causes pollution to the environment through various kinds of emissions. The severity of this problem is continually increasing, which is becoming a global environmental problem that threatens not only the economy but also human life. Energy is one of the critical resources for running the economy and traditionally has had large carbon footprints. The main primary resources of energy used are still fossil fuels. The energy consumption has been continually growing (Figure 1) and will keep growing in the future as a result of economic development.

Global energy reports have demonstrated that, while the total expenditure of energy consumption has doubled, the structure of energy consumption by economy sectors has not changed for the past 45 years (Figure 2). The industrial energy consumption is still one-third of the final demands, which proves industry as one of the primary pollutant emitters. Industrial energy efficiency is one of the hot topics since the energy crisis of the 1970s of the last century. One of the most efficient methods that may con-

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siderably reduce industrial energy demands is Process Integration (PI). It started mostly from heat integration [2] for targeting and efficient energy recovery in process industries [3] and economics of heat exchanger networks (HENs) [4], applying the separate design of process subsystems [5]. Alternatively, Mathematical Programming (MP) has been used for process optimisation [6] and HEN synthesis [7]. The progress was accelerated by using computer technologies and the development of optimisation techniques. Both methodologies were competing through the years and recently have generated several hybrid methods.

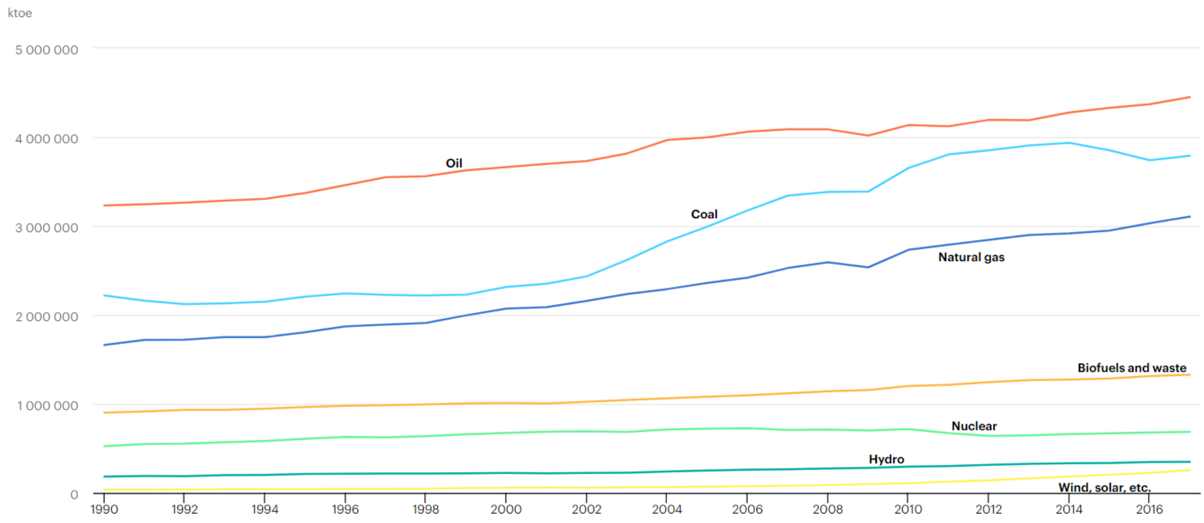

Fig.1. Total primary energy supply by source, World 1990–2017 (in kilotons of oil equivalent) [1]

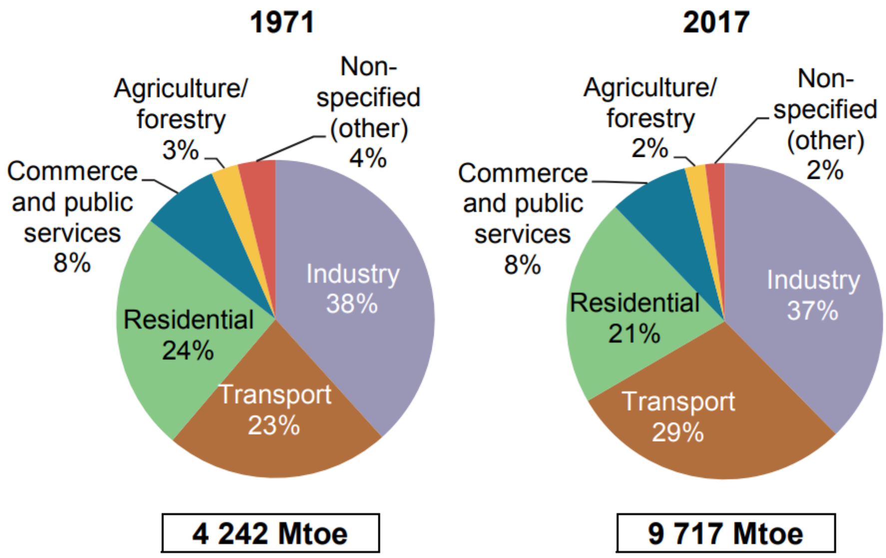

Fig. 2. Total final energy consumption by sector [1]

Over the years, PI has grown into a scientific area of its own, comprising a family of methodologies for resource-saving and emission reduction [8]. According to the definition of the International Energy Agency, PI is a set of “systematic and general methods for designing integrated production systems ranging from individual processes to Total Sites, with particular emphasis on the efficient use of energy and reducing environmental effects” [9].

Figure 3 demonstrates the main parts of heat integration for efficient energy use and emission reduction. It starts from the thermodynamic analysis of process streams and the application of Pinch technology [10] that was later extended to utility efficiency [11] and distribution [12], as well as the integration of distillation columns, reboilers, and reflux condensers [13]. Besides, the heat flows in the distillation column were additionally analyzed to identify horizontal heat transfer to get energy benefits [14]. Gas and steam turbines, heat pumps, and cooling cycles may also be integrated efficiently to the industrial systems [15]. Process intensification technologies, when applied jointly with PI, provide more degrees of freedom when analysing process systems under operation [16]. It gives more flexibility for the retrofit of process plants as well as the reduction of investments and operation cost of the new design [17]. The consideration of several industrial processes is a step-up for a new plant concept [18]. This provides an approach that can reduce energy demands and emissions on an industrial site while simultaneously avoiding loss of cogeneration efficiency [19].

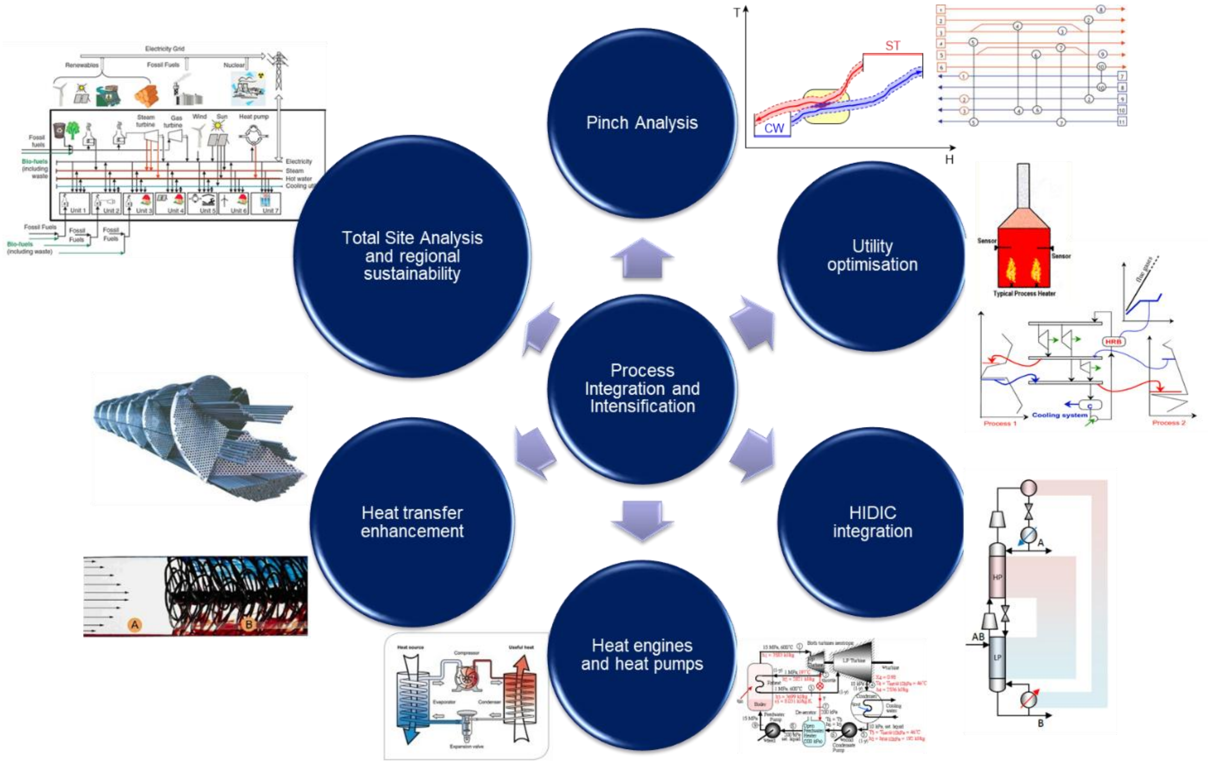

Fig.3. The overview of heat integration application areas

2. The State-of-the-Art Review

Many follow-up approaches have been developed and published in many research papers, guidebooks, and case studies since PI was introduced. Some recent developments have changed the trend of the processing industry and system engineering and proposed new process engineering concepts. This paper touches some of them to show the readers the directions of their applications.

2.1. Heat integration

Heat integration of continuous processes may be divided into three main groups based on the approach used: Pinch-based approach methods; MP-based methods; and hybrid methods. Pinch-based approach methods are mainly applied for the concept design of new processes [20] and less suited for retrofit. Gadalla proposed a new graphical visualisation for aiding in the retrofit of process system HENs [21]. It is based on the representation of each heat exchanger by line with the slope that corresponds to heat capacity and flow rates. This approach was later used for the analysis of a new crude oil refinery, saving 10.5 % of primary energy with minor HEN modifications and the plant layout [22]. Akpomiemie and Smith introduced an alternative method of HEN retrofit by area ratio approach [23] and pressure drop consideration [24]. As a result of these approaches using a combination of Pinch methods and enhancement during structural modifications, the reduction of the capital cost of the retrofit was reduced [25]. The Monte Carlo simulation model is also successfully applied to the optimisation of industrial systems, for example, heat recovery loops [26] and HEN design [27]. The case studies of kraft pull mill’s HEN demonstrated the design features with similar steady-state performance. Bonhivers et al. proposed the method of bridge analysis as a complementary development of Pinch Analysis (PA), allowing analysis together of the HEN and the process it serves [28]. The energy transfer diagram and heat exchanger load diagram were considered to construct utility paths, reducing energy consumption [29].

Optimisation-based approaches mostly use MP, providing linear and nonlinear formulations [30]. A new disjunctive formulation for the simultaneous optimisation and heat integration of process systems together with utility selection was presented in [31]. The robustness and the efficiency of the alternative mixed-integer reformulation against the Big-M and hull reformulation were compared and tested by different solvers [32]. Mixed-integer nonlinear programming (MINLP) was successfully used to obtain the trade-off between availability and cost, considering two parallel units at a chemical plant [33]. The proposed bicriterion model maximized net profit, optimizing process flow diagram of two industrial case studies: a methanol synthesis and a toluene hydrodealkylation.

The development of high-fidelity models is one of the most prospective ways to the industry digital transformation and coupling with PI and intensification becomes a very powerful tool. Burnak et al. presented a unified theory and framework for the integration of process design, control, and scheduling [34]. The proposed framework was based on the offline surrogate model. Explicit model predictive control schemes were developed and used to real plant data. The framework was demonstrated on: (1) a system of continuous stirred tank reactors; and (2) combined heat and power network for the residential sector. Avraamidou et al. proposed a new algorithm to resolve problems regarding trilevel mixed-integer quadratic optimisation. The problem of concern was complex because it consisted of integer and continuous variables at all levels of optimisation [35]. In different sectors, such as HEN synthesis with utility scheduling [36], hybrid electric and thermal powertrains [37], and urban energy supply, multiobjective optimisation may be applied in solving the problem, considering the energetic, economic, and environmental targets [38].

Both MP and graphical approaches have disadvantages; for example, MP does not have any insights into the problem and can be time-consuming. The graphical approach cannot provide an automated optimisation of process design or retrofit. This gap may be fulfilled by hybrid approaches [39] to improve the opportunities of existing methods [40]. The combination of Pinch approach and MP reduced the problem by graphical insights [41] and proved the solution close to the global optima [42]. Some approaches were initially developed and later transformed into hybrid methods with further modifications. They are vertical mixed-integer linear programming (MILP) transshipment model [43], network Pinch [44], hypertargets [45], heat transfer enhancement [46], TransGen [47], and time super targeting [48], etc.

All those approaches have had a wide application in various sectors to both grassroots and retrofit optimisation. Since the development of the methods, they have been applied in industry, and recent industrial case studies indicate a significant potential for energy savings and emission reduction. PI plays a key role in such global trends as energy transition [49], industry digital transformation [50], and the circular economy [51]. Some of the applications include cement production in Croatia [52, 53], chemical production in Sweden’s largest chemical site [54], oil refining [55, 56], coke and chemical production in Ukraine [57, 58], steel manufacturing [59], natural gas and refining and utilization [60], biofuel production applying distillation and pervaporation [61], milk production [62], and cheese manufacturing [63].

In analysing a batch process system, additional modelling elements are considered, such as time slices and availability of process equipment. In this case, the approaches are based mainly on proper scheduling, coupled with heat integration [64]. Direct heat integration and indirect heat integration produces the minimisation of primary energy use in multipurpose batch processes. The direct pattern involves heat exchange between concurrently active streams, and the indirect pattern involves advanced heat storage [65]. MILP was used to optimise the number and allocation of pumps for the batch process [66]. At the same time, the plant layout and optimal scheduling of the batch processes were generated with variable material transfer times. The methodology and a case study of batch plant processing were proposed in [67] to maximize the availability of hot and cold process stream pairs with feasible temperature driving forces accounting scheduling constraints. It reduced the time for heating and cooling in process steps and resulted in production improvement with lower energy consumption. Intermittently available continuous streams may also be analysed together with batch processes. The application of the model reduced the energy input by 30 % and the product output by 15 % [68]. To reduce the computation time, a genetic algorithm is proposed for the scheduling of multipurpose and multiproduct batch processes. The case study proved 98.53 % time-saving for a solution close to the global optimum.

Proposed many years ago [69] was an approach that analyses the utility system by R-curves [70] [69] and also an initial concept of simultaneous optimisation of several processes reducing the utility consumption of a site-wide system. Later, the Total Site Analysis (TSA) was focused by many kinds of research, and different concepts and developments were published. Some researchers exploited it for the development of the methodology for thermodynamic cycles integration [72], and the identification of waste heat potential of industrial sites [71].

Other approaches optimised an operation mode of Total Site under uncertainties, such as electricity price fluctuations and steam power demand changes [73]. A Total Site utility system may be designed by different methods; for example, in [74], the P-graph framework was used for this goal. A hybrid power system (HPS), using the integration of the process heat supplies and demands, was proposed in [75]. The heat recovery through a Total Site network was investigated to reduce the capital cost [76] upon design and retrofit of Total Site HEN [77]. The method of both isothermal network synthesis and nonisothermal network synthesis was proposed in [78]. The TSA was applied in large industrial sites and various industries [81], such as cement [79] and refinery [80].

2.2. Mass and power integration

The minimisation of resources in process industries based on mass integration principles, such as reuse, consumption minimisation, driving force changing, is a very complicated task from a different point of view. The minimisation of wastewater in the process industries is becoming more problematic due to water scarcity and purity issues in urban areas. The approach to water use allows individual process constraints related to minimum mass transfer driving force, fouling, corrosion limitations, etc., which may be easily incorporated. Both single and multiple contaminants are addressed. The multiple-contaminant case requires formulating multiple constraints related to modelling the problem adequately [82].

The Pinch approach may also be used for a minimum waste generation target before the detailed network structure. A graphical method was proposed in [83] to understand the targets, and it was implemented by the Source Composite Curve. A minimum waste targeting algorithm was developed to solve different kinds of tasks, for example, hydrogen and water recycling, reuse, and management. A rigorous mathematical decomposition model was later proved to demonstrate the potential applications of the site water network and energy sector with intersectoral fuel use [84].

In another research, an MINLP problem was used to develop large-scale water networks within industrial cities [85]. Various scenarios of industrial wastewater reuse at different processing facilities were considered, and intermediate water treatment interceptors were tested. The interplant water use is more economical, and an interplant chilled and cooling water network was analysed to obtain cost savings [86]. There are network reliability problems due to the consistency of sources' availability and cost-saving allocations for network synthesis, and a decision-making tool was developed to get more feasible solutions and satisfy plant demands.

A new concept of one-way centralised water reuse header was recently proposed in [87] for water optimisation at site plant systems and simple interplant water reuse and exchange. It is supposed to be operated by a third party, allowing the operator to protect users' proprietary information and confidential data. The Total Site freshwater requirement and wastewater generation were lowered by 72.3 %, while, simultaneously, the piping and pumping costs were reduced.

A graphical method was proposed in [88] to evaluate the minimum consumption of resource for water and hydrogen networks. The approach substituted the flow rate and concentration constraints by hydrogen load and relative concentration. A hydrogen network optimisation was also automated and presented as a computer-aided procedure to solve a problem at a refinery [89].

A hybrid carbon-hydrogen PA was proposed to analyse hydrogen supply networks [90]. Refinery hydrogen network is a typical task for hydrogen PI study. A new method for the simultaneous integration and optimisation of the hydrogen separators and a hydrogen network was proposed in [91]. The proposed model of an integrated system adjusted the hydrogen utility, and the case study demonstrated the reduction of hydrogen consumption by 2.39 %.

The methodology for CO_2 emission Pinch Analysis has put forward the idea to identify the optimal energy mix and extend the method of energy and emission targets for renewable sources [92]. Coal power plants with new CO_2 capture units using solvent absorption were analyzed in [93] to reduce the energy penalty by 50 % through the integration of the CO_2 capture and storage into coal-fired power plants.

The power integration methods for the design and optimisation of HPS are still being developed. By considering various storage technologies in [94], a Power Pinch Analysis tool, using the AC/DC modified storage cascade table has been developed to optimize the HPS. The extended Power Pinch Analysis was developed in [95] for the optimal design of renewable energy systems with hydrogen storage. The optimal sizes of the diesel generator and all components of the hydrogen system were calculated to minimise the total annual cost. Authors have delivered a methodology that is even more advanced by incorporating trigeneration. The proposed approach TriGenCT with energy storage can save energy up to 202 GWh/y [96]. Another interesting approach assesses the energy losses in HPSs for optimal sizing of storage capacity [97]. The case study demonstrated up to 30 % reduction of existing energy storage.

2.3. Process intensification

The main challenges of the process industries are to produce the product of appropriate quality, minimising environmental impact. In this paradigm, PI is closely connected to process intensification technologies that help material recycling [98]. Contributing to cleaner production, developing engineering solutions, and extending the scope of integration to cover energy, materials, water, and supply chain, process intensification influences the circular life cycle and the economy [99]. A general framework for process design, integration, and intensification was described by [100] to present different intensified and local phenomena at the lowest level, various tasks at the equipment level, and various unit operations at the flowsheet level.

Heat transfer intensification can be applied using local phenomena that may substantially improve process parameters [101]. In some specific industries, for example, in a refinery where the fouling problem contributes a lot to energy efficiency, this problem is very important [102]. This problem may be resolved by predictive management of the crude oil distillation unit, which may provide substantial CO_2 and operating expenses (OPEX) saving [103]. This was also proven when analysing retrofit options for a crude oil distillation unit, accounting for fouling and the cleaning schedule [104].

Numerous case studies were analysed in different processes to prove a significant input of process intensification technologies. For example, new cellulosic ethanol production was developed in [105], and the energy recovery was optimised by vapour recompression and waste heat utilisation. As a result, 42.8 % of the utility energy consumption was reduced, and the specific energy consumption was lowered to 23.9 MJ/kg for ethanol.

The intensification of mass and heat transfer contributes to process efficiency increase, influencing the energy, resource efficiency, and the capital cost of the equipment. Reactive distillation, combined with other intensification technologies, leads to the discovery of new processes and applications [106]. It can surpass equilibrium limitations, simplify complex processes, increase product selectivity, and improve separation efficiency by intensified distillation technologies, such as dividing-wall column, HiGee distillation, cyclic distillation, heat-integrated distillation column, membrane-assisted distillation, microwave-assisted distillation, and ultrasound-assisted distillation [107]. Through the use of a heat pump-assisted azeotropic dividing-wall column, the energy consumption of biobutanol processing was reduced by 58 % [108]. Another case study proved the energy consumption reduction of 21 % by thermally coupled distillation for hydrotreating process of biojet fuel production from *Jatropha curcas*.

3. Process Integration in the CIS Countries

The Commonwealth of Independent States (CIS) includes countries that were formed after the breakup of the Soviet Union. Now CIS comprises nine countries: Armenia; Azerbaijan; Belarus; Kazakhstan; Kyrgyzstan; Moldova; Russian Federation; Tajikistan; and Uzbekistan. The total population of the CIS is about 240 million people, and the GDP is 2,026,657 million USD. The distribution of the GDP per capita is presented in Figure 4 [109].

PI in CIS has been developed starting from the late 1990s of the last century since the British Council support of collaboration between the Kharkiv Polytechnic University and the University of Manchester Institute Science and Technology, now the University of Manchester, the birthplace of PI. The first group to step up to this new direction of interdisciplinary research came from the school of Professor Tovazhnyansky [110]. There has been a lot of research that was supported by international collaborative projects in the past 15 years.

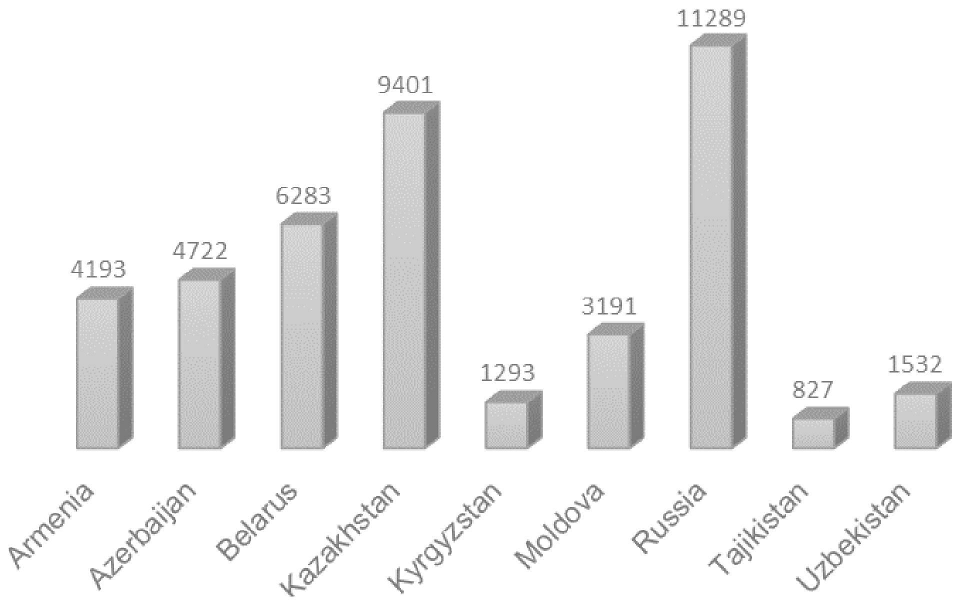

Fig. 4. GDP per capita for CIS as of 2018, based on data from [109]

The development and application of heat pumps with the use of environmentally friendly refrigerants were delivered by the support of the Sustainable Heat and Energy Research for Heat Pump Application project and using the integration concept of heat pumps for food industry [111] and building heating systems [112]. With the possibility to use it in cheese and milk production being indicated, the use of the waste heat of an ammonia refrigeration cycle was analysed. Two options were considered in applying additional compression to increase heat recovery. Another case study was implemented in building heating systems. Economic efficiency of both cases is very high with the payback of the investments of one year.

Sodium hypophosphite production was analysed during ECOPHOS project, and new heat-integrated flowsheet was proposed to save up to 45 % of primary energy consumption [113]. The process is a complicated chemical site that has a low degree of energy recovery and a high margin of the product was analysed. These two were the main reasons that in-depth energy analysis was avoided when it was designed. The proposed retrofit transformed an initial flowsheet to heat recovery network that can additionally contribute to plant economic efficiency.

Process intensification technologies were developed under the INTHEAT project, and the application to biofuel production was studied [114]. Taking into consideration the energy requirement of ethanol mixture concentration gained during fermentation until high quality is obtained with the use of different membranes, an analysis was conducted. Also analyzed were how the specific energy demand of the process varies during the pervaporation process and how energy consumption can be reduced, applying pervaporation processes with different operating modes.

The energy-related project Efficient Energy Integrated Solutions for Manufacturing Industries (EFENIS), which includes the capital investment of Total Site heat recovery [115], Total Site power cogeneration [116], and application in chemical [117] and coke-to-chemical [118] industries provided a significant contribution. The methods for the minimisation of heat transfer area during Total Site recovery network design and the reduction of expansion section of steam headers among cogeneration opportunities were proposed. Several representative case studies provided validation of these proposed approaches. The utility consumption of a bromine chemical site was reduced, saving 800,000 EUR/y and having a payback of 20 months. An analysis of a Ukrainian coke-to-chemical site was performed, and an energy-saving of 2.8 MW with a nine-month payback of the investments that amounted to 430,000 USD was identified.

Some other methods were proposed to utilize the energy-saving potential in the Ukrainian oil refineries [119] from 2001 to 2014, where energy expertise and detailed analyses were provided to the managers of crude oil distillation, coke formation, hydrotreating, reforming, and other units. Loads of heating and cooling utilities were optimized to cover site demands, and the innovative application of heat pumps for hot water supply systems was also considered [120]. The specific energy demands of oil refineries with different capacities were estimated.

The energy-saving measures were structured, and a roadmap for investors was proposed. The general pathways for energy reduction up to 60 % from the existing level were proposed.

There were some research and developments by other schools in collaboration with leading Process Integration laboratories and centres. The Atyrau Refinery was analysed by teams from the Nazarbayev University and the University of Manchester. Opportunities for the application of the Organic Rankine Cycle were evaluated [121]. Furthermore, the energy-saving potential was evaluated via energy targeting using PA, and an improved HEN was proposed, saving 43,885 tons of CO_2 per year. Computer-aided analysis of waste utilisation in the phosphoric acid industry was performed in [122]. The phosphoric acid industry in Kazakhstan and Russia was analysed, and the results aggregated in an applied software tool with the use of Continuous Acquisition and Life-cycle Support technologies [123]. PA was used for the improvement of HEN in styrene production, and the recommendations of ethylbenzene dehydrogenation retrofit were proposed [124]. The authors reported that the flexibility of the process was increased as well as energy recovery; the primary energy consumption was reduced by 25 %. There are some applications of MP for simultaneous design of HEN and distillation columns with improved heat integration [125]. Later the authors proposed a method for the synthesis of an economically optimal HEN [126]. The methodology is based on system decomposition with fixed variables, and both retrofit and design problems were successfully implemented.

4. Discussion

Several global challenges should be discussed additionally, assessing the potential of the CIS countries. Energy efficiency in the process industry is still a big issue and improvement can be achieved by developing process integration and intensification technologies. In close cooperation with the industry and governmental bodies, this may start from the creation of centres of excellence within a university environment. Industrial support and interest should stimulate the technology developments, while governmental support can potentially help with developing the legal base, stimulating energy-saving and clean technologies. Accounting for the vast territory and the variety of industries and research environments, the process integration network may be created in time and include participants from all three types of institutions.

Different industry types in the CIS exist in many industrial parks and large sites; most of them are situated in the Russian Federation. Belarus has several refineries and a sizable food processing sector. Large chemical sites, metal processing sites, oil refineries, and mining sites of different mineral resources are placed in Kazakhstan. Chemical industry sites are also present in Uzbekistan. Various oil refineries, chemical sites, and food processing sites are located in Azerbaijan and concentrated in a small territory close to big cities.

Russian industrial sites should be analysed additionally. Most of them are concentrated in the European part, but the Asian part has larger sites that include mostly process industries. According to [127], the distribution of industrial sites by regions is as follows:

- Central Federal District: 135 sites;
- Northwestern Federal District: 64 sites;
- Southern Federal District: 27 cites;
- North Caucasian Federal District: 14 sites;
- Volga Federal District: 64 sites;
- Ural Federal District: 23 sites;
- Siberian Federal District: 21 sites;
- Far Eastern Federal District: 11 sites.

Cross-sectoral integration is a perspective measure for the reduction of primary energy resources and the improvement of the environmental condition of industrial regions. Waste heat from industry is a potential source of energy for district heating and cooling. The heating and cooling capacities have different relevance for different CIS members. Cooling is more relevant for southern regions, while the heating is essential for the northern territories having a colder climate. This issue affects the business model of interplant cooperation and establishing partnerships between energy companies and municipalities or district heating companies.

Energy integration between industry and residential or commercial sectors can provide further opportunities for the utilisation of primary energy sources. This can be made possible via the combined generation of heat and power and proper energy targeting based on thermodynamic analysis and utility minimisation. An essential measure, as mentioned earlier, is to arrange a transition from linear economy patterns to circular economy patterns, which aims to solve recycling resources and managing of emissions [128]. Additionally, the energy demands might be covered by renewable sources that could be applied successfully for industrial use, as is shown in [129]. This issue, however, should be appropriately analyzed accounting for the regional specifics, for examples, climate, remoteness, and economic efficiency, to be attractive for potential investors.

Renewable energy plays a more important role in modern society, providing capacity for an energy transition that is propagated to all parts of the economy. The economy is becoming more integrated, posing challenging global problems, for example, the food-water-energy nexus. The role of PI is to find an optimal solution for global supply chains [130]. In terms of interconnection and control, the electrification of the industry is one of the possible scenarios for future energy systems.

PI measures are sometimes complicated to identify, especially considering the multitude of potential solutions and the need to make the optimal choice. The use of advanced methods and software tools to optimise the savings and efficiency improvements is necessary [131]. This issue is in line with the transforming digital society that affects the industry as well. Therefore, the use of PI and Total Site integration items for online process optimisers and process control approaches to improve the energy and resource efficiency of industrial clusters is required.

There are many mineral resources in the territory of the CIS countries, which need to be supplied with energy and water and be environmentally friendly, that are in use and also will be explored, mined, and processed. The use of PI may provide such solutions and save from both capital expenditure and OPEX of future resource processing projects, design of new plants, and modernisation of existing facilities. The resource base and process industry of the CIS concentrated mainly in Russia and Kazakhstan and usually at the abandoned areas where the application of the integrated solution is more efficient.

Chemical industry mines require different raw materials to provide the end products. They are common, such as potassium salts, phosphorites, apatites, and sulfur. Chemical plants produce organic and inorganic products like chemical fibres, mineral fertilizers, synthetic rubber, chlorine, sodium, sulfuric acid plastics, synthetic resins, and others. The production facilities are placed in Solikamsk, Berezniki, Egoryevskoye, Tula oblast, Smolensk region, Togliatti, Novgorod, Magnitogorsk, Nizhny Tagil, Lipetsk, and Cherepovets in Russia; South Kazakhstan; and Uzbekistan. Synthetic rubber, plastic, and synthetic resin facilities are located in Efremov, Tula region, Yaroslavl, Voronezh, the Urals, Krasnoyarsk, and Western Siberia. Over 85 % of the gas is produced in Western Siberia and then exported to the CIS, Baltic states, and abroad [132].

5. Conclusion

There have been some initial developments in PI technologies in CIS countries, but its potential is much higher. As can be seen from the analysis, most of the PI research and implementations were results of joint international projects funded by the European Union. It is necessary to have in-house methods and schools of thought for the method to show its full potential in terms of both research and practical results.

Many industrial clusters could be the basis for potential future developments. Besides, waste energy from the industry may be utilized in the transport and residential sectors. Demonstrating a research gap and capacity for the development of scientific schools are recent developments in PI methodologies, bearing in mind an application potential. Such developments may improve the energy efficiency in industry, utility generation, energy interconnection, and energy partnering of all market players. Thus, the economic potential of the CIS may be used more efficiently, and the development of these countries will be in line with the global trends, such as sustainability and circularity of economic flows.

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