Paving the way for the Paris Agreement: Contributions of SDEWES science

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A b s t r a c t

Today, coal is responsible for 40% of annual CO_2 emissions. At the same time, global warming causes climate changes accompanied with catastrophic meteorological phenomena all over the world. After the 2015 Paris Agriment many countries set ambitious energy policy to reduce the annual greenhouse gas emission. The 2021 UN Climate Change Conference, COP26 - Glasgow, ended with the adoption of a less stringent resolution than some anticipated: countries only agreed to *"phase down"* rather than *"phase out"* coal. Is possible the realization of the Paris Agreement after COP-26? For achieving this ambitious targets in such conditions, the support of the multi-disciplinary scientific knowledge is needed. Since 2002 a series of SDEWES Conferences were founded. This paper presents an overview of published researches in special issues of leading journals dedicated to the series SDEWES Conferences, including also the papers in current special issue presented on Conferences held in 2020: 2nd LA SDEWES Conference - Buenos Aires, 1st AP SDEWES Conference - Gold Coast, 4th SEE SDEWES Conference - Sarajevo and 15th SDEWES Conference - Cologne. The focus is on five main fields: (1) energy system analysis; (2) energy savings in the building sector; (3) district heating; (4) electrification of transport and (5) water-energy nexus. Undoubtedly, the researches presented in this special issue as well as in previous ones, will contribute to the achievement of the goals of the Paris Agreement in difficult conditions after COP26.

Keywords: SDEWES, Energy system analysis, Renewable energy sources, District heating, Low-energy buildings, Electrification of transport, Water-energy nexus

Contents

1. Introduction

The increasing depletion of natural resources, combined with the associated environmental and global climate damage, has highlighted in the 21st century the need for a more efficient use of energy and use of renewable energy sources. There is a an urgent issue that efficiency must increase across all links of the energy chain, from generation to final consumption, to improve economic and environmental sustainability [1, 2] and that renewable technologies with potential zero carbon footprints must replace based on non-renewable fossil fuels [3]. Fossil fuels are the dominant energy source in the world today, with a total primary energy production of about 80 % [4]. Unfortunately, recent studies warn against countries planning to produce more than double the amount of fossil fuels by 2030 [5].

At the same time, greenhouse gas emissions are also increasing, which is not in line with a 1.5 ^{O}C temperature limit, causing during 2021 several meteorological catastrophic events all over the world.

The water levels of the Paraná river, the second-longest in South America after the Amazon, are at their lowest since 1944: flow rate has dropped from an average of 17,000 m^3/s to just 6,200 m^3/s, Fig. 1.a [6]. It caused problems for energy production with the hydroelectric plant that running at only 50%. The river is key to commercial shipping and fishing but also provides 40 million people with drinking water.

In July 2021 heavy rains swept across western Germany and the neighboring countries of the Netherlands and Belgium, Fig. 1.b [7]. Small rivers and streams turned into torrential currents that destroyed entire villages. It became one of the region's worst natural catastrophes in recent generations. Many people died and many more lost their homes and belongings.

On August 16, 2021 more than 170,000 km^2 have burned across Northern Siberia – Russia, making the 2021 the worst in a decade with regard to fires, and possibly ever, Fig. 1.c [8]. That's an area about the size of the U.S. state of Florida. This is about climate change: Northern Siberia has seen unusually high summer temperatures over the past couple year. In June, 2021 the Arctic Circle town of Verkhoyansk, about 675 kilometers north of Yakutsk, reported the highest-ever temperature recorded in the Arctic: 38.2 ^{O}C.

Also, in other parts of the world, fires have ravaged: Algeria, Turkey, Greece, Italy, Spain, USA, etc. In the USA, the largest fire was in California, the so-called Dixie Fire, which burned nearly 3,000 km^2 - about the size of Luxembourg [9].

A tornado with velocity of 219 km/h has swept through several villages South Moravia in the Czech Republic, killing five people, leaving more than 150 others injured and around 1,000 homes had been destroyed, Fig. 1.d [10]. Tornadoes are not common a metrological phenomenon in these parts of the world.

In the Pacific Northwest, rising water temperatures could be a death sentence for Pacific salamon because salamon metabolism is extremely sensitive to temperature [11]. In the

Thermaic Gulf near Thessaloniki in northern Greece extreme heat devastated Greek mussel harvest [12]: *„mussels were boiling in their environment."*

In Cordoba, a province with a city of the same name in northern Argentina, which has a mild climate, and even in the winter months there the temperature does not fall below 10 °C, heavy snow fell [13]. At the same time in the capital Nuuk in Greenland in December the temperature was 13 ° C while at this time of year the average temperature is -5.3 °C [14].

Therefore, in the current global society context, climate change represents an urgent issue that has encouraged many researchers to investigate renewable technologies with potential zero carbon footprints [15].

a) b)

c) d)

Fig. 1. Several meteorological catastrophic events all over the world caused by the global temperature rise due to greenhouse gases emissions: a) the drought of the Paraná river [6]; b) floods in Germany [7]; c) fires in Northern Siberia [8]; a tornado in the Czech Republic [9]

The 2021 United Nations Climate Change Conference, more commonly referred to as COP26, was the 26th United Nations Climate Change conference, held in Glasgow from 31 October to 13 November 2021. Delayed for a year due to the COVID-19 pandemic it was the 26th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), the third meeting of the parties to the 2015 Paris Agreement (designated CMA1, CMA2, CMA3), and the 16th meeting of the parties to the Kyoto Protocol (CMP16) [16]. The conference was the first since the Paris Agreement of COP21 that expected parties to make enhanced commitments towards mitigating climate change; the Paris Agreement requires parties to carry out a process colloquially known as the 'ratchet mechanism' every five years to provide improved national pledges [17]. The result of COP26 is the Glasgow Climate Pact, negotiated through consensus of the representatives of the 197 attending parties. Owing to late interventions from India and China, that weakened a move to end coal power and fossil fuel subsidies, the conference ended with the adoption of a less stringent resolution than some anticipated: countries only agreed to *"phase down"* rather than *"phase out"* coal

[18]. Nevertheless, the pact is the first climate deal to explicitly commit to reducing the use of coal. It included wording that encouraged more urgent greenhouse gas emissions cuts and promised more climate finance for developing countries to adapt to climate impacts [19].

All of the above point to the importance of SDEWES conferences. Therefore, from the beginning of the 21st century, since 2002, a series of Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conferences were founded. Over the years, SDEWES Conferences have continuously increased considering the number of participants-researches, research papers, covered topics and parallel activities as thematic panels, key-note lectures, etc. Now, SDEWES Conferences are one of the most relevant in the world, held every year, not only in Dubrovnik but around the world. In 2020, one SDEWES conferences was in-live (2nd Latin American SDEWES Conference, 9 – 12 February 2020, Buenos Aires, Argentina), while three SDEWES conferences were on-line due to the COVID-19 pandemic (1st Asia Pacific SDEWES Conference, 6 – 9 April 2020, Gold Coast, Australia; 4th South East Europe SDEWES Conference, 28 June – 2 July 2020, Sarajevo, Bosnia and Herzegovina and 15th SDEWES Conference, 1 – 5 September 2020, Cologne, Germany.

From the 1st Conference held in 2002, Energy – The International Journal, has continuously dedicated Special Issues to this Conference Series, in which the selected papers offer a comprehensive view of up-to-date reserch activities in the field. This review paper is part of the Special Issue of Energy dedicated to the aforementioned four SDEWES conferences. The Conferences covered various research topics. This review paper aims to provide an overview of identified topics which have gained increasing attention in past special issues of SDEWES Conferences, dealing with the same topics addressed in present Special Issue, with the aim to provide an overview of the development of the research performed by the researches participating to the SDEWES Conferences in order to highlight the recent progress of the research in these identified topics [20-22]. This identified topics are:

- ✓ Energy system analysis;
- ✓ Energy savings in the building sector;
- ✓ District heating;
- ✓ Electrification of transportation
- ✓ Water- energy nexus;

It is necessary to emphasize that there is no clear boundary between certain topics, but there is mutual interaction.

2. Energy system analysis

To this scope, several actions are required, such as: high penetration of renewables – to 100% renewable energy systemes, island energy sytems, demand plaaning and development of energy planning tools.

2.1. High penetration of renewables – to 100% renewable energy systemes

Renewable energy offers a sustainable alternative and is considered to be 'the energy of the future' [23]. The problem with achieving fully 100% renewable energy systems is the intermittent nature of energy sources like wind and solar. Depending on the day of year and weather, there may be an excess or shortage of electricity in the grid, so energy storage and demand response technologies need to be introduced to stabilize the system [24]. It has been shown that even the use of low capacity energy storage can drastically ease the job of balancing electricity generation and demand [25]. So, adding electric vehicles and demand response technologies to the national energy systems augmented the integration of wind-generated electricity without the excess of electricity production. Flexibility with Vehicle-to-Grid (V2G) systems showed excellent potential for additional power system flexibility by using heat from heat pumps, heat storages, and combined heat and power plants [26-28]. Another way to achieve 100% renewable system would be through obtaining a large amount of energy from the wind, which would request to use of expensive technologies for energy vectors such as hydrogen [29] and fuel cells or any other fuel cell technology [30]. Analysis of decarbonization and achieving 100% renewable energy system was performed for different countries and regions.

The study by Dominiković et al. [31] presents the transition steps to a 100% renewable energy system which need to be carried out until the year 2050 in order to achieve zero carbon energy society. The resulting power generation mix shows that a wide variety of energy sources need to be utilized and no single energy source has more than a 30% share. In paper by Prebeg et al. [32] a proposed two-level approach with multi-objective optimization on the global level, was used to design a Croatian Energy System, where electric vehicles are integrated to serve as battery storage in (V2G) mode, for a scenario between 2015 and 2050. In study by Chung et al. [33], an engineering economics software was developed to find the optimum design of renewable energy systems in micro-grid, off-grid, and on-grid cases, which provides useful information for investment decisions. The study by Hrnčić et al. [34] investigates the possibility of achieving a 100% renewable energy system in Montenegro that would meet the requirements set out in a European Green Deal. Two scenarios simulated and analysed in the EnergyPLAN model, Fig. 2, with different dynamics of integrating renewable energy sources in the energy system. Due to the large potential, hydropower plants will have a significant share in the production of electricity, but special attention was given to the integration of variable renewable energy sources like solar and wind energy. The analysis shows that it will be possible to achieve a 100% renewable energy system in both scenarios.

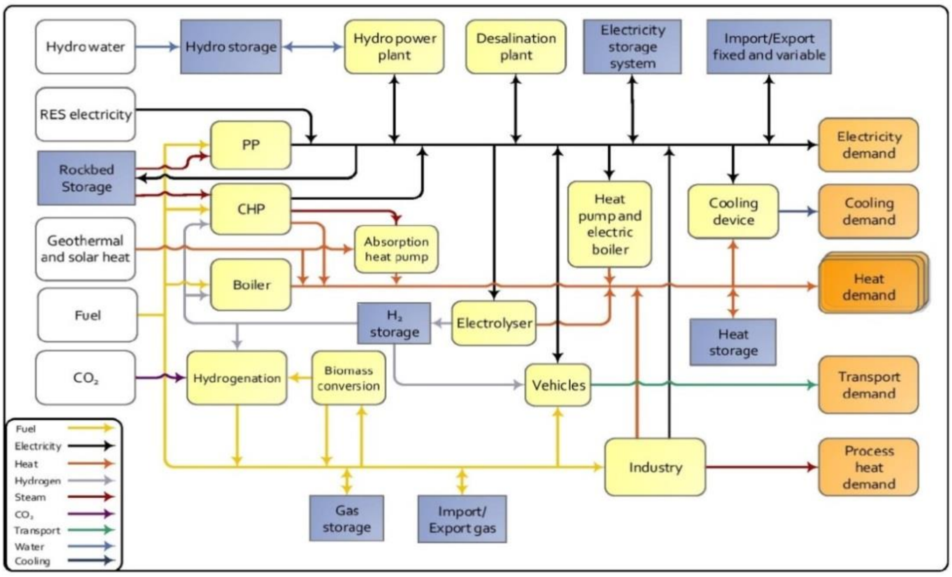

Fig. 2. Schematic diagram of the EnergyPLAN model used in [34].

In paper Sarasa and Turner [35] evaluate a combination of efficiency initiatives to deliver both reduced energy use by households and a more sustainable supply of energy. Their findings suggest that a package aimed at improving efficiency in household electricity and petroleum use, combined with a more competitive supply of energy from renewable sources, may be the only way to get reductions in all energy use, and thus benefit the economy.

2.2. Island energy systems

Energy planning of islands is becoming increasingly important as the EU increases its effort to tackle climate change [36, 37]. Islands are considered to be unique areas because of many disadvantages they are exposed to such as a weak electrical grid connection, higher fuel prices, overall weaker infrastructure, etc., but they offer a possibility to have a clearer overview of needs and resources available and often have better solar and wind potential than on the mainland.

The paper by Dorotić et al. [38] presents a novel approach for defining energy system of a carbon neutral island which utilizes only intermittent renewable energy sources in combination with vehicle-to-grid concept as a demand response technology, where marine transportation has also been taken into account. Islands in the Mediterranean Sea are normally fed by a stand-alone electrical grid and a power plant, equipped with diesel engines. In order to improve the sustainability of the energy sector, the study by Curto et al. [39] starting with the analysis of the electrical energy consumption of public buildings, suggests a more sustainable energy mix, based on solar and sea wave. In paper by Marczinkowski and Østergaard [40], investigation of two potential approaches (Battery Energy Storage Systems (BESS) and Smart Energy System (SES)), for the Danish island Samsø and the Orkney islands in Scotland, shows that BESS tend to address only the electricity sector, while TES furthermore improves issues in the heating sector and enables possibilities in the transport sector. Because of islands represent areas where it is possible to have a clear overview of resources and needs over a large number of sectors, Mimica and Krajačić developed in [41] Smart Islands method, Fig. 3, which automatically combines needs and resources based on the quantitative indicators and generates energy planning scenarios with precisely defined types and the capacities of required technologies. The obtained results indicate that the Smart Islands method can be applied to islands with different characteristics as well as suggest optimal energy planning scenarios while meeting needs with local resources.

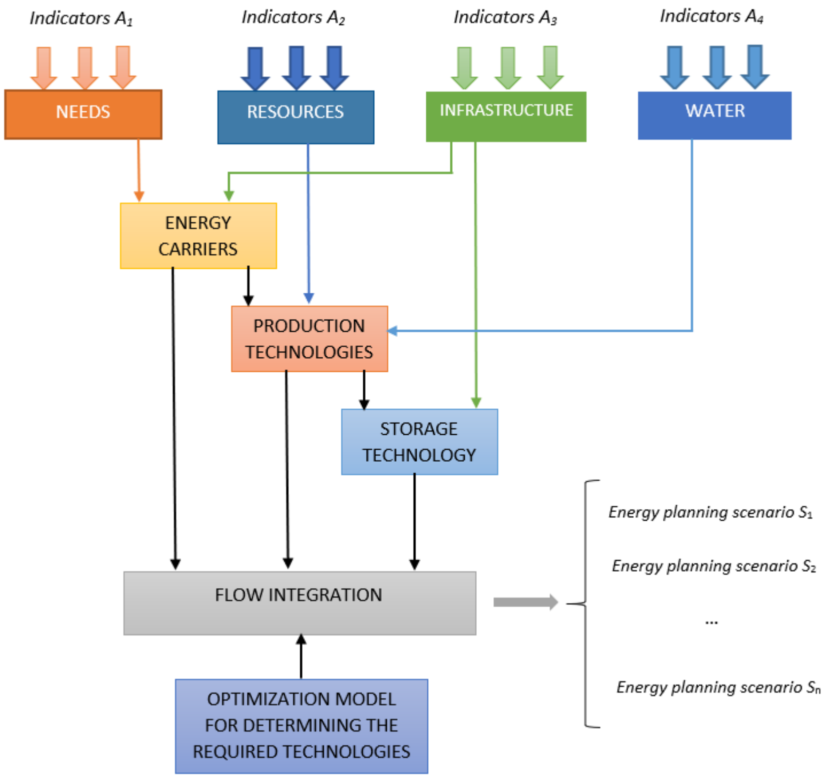

Fig. 3. Smart Islands method for defining energy planning scenarios [41].

2.3. Storage v.s. grids

Energy storage systems could play a crucial role in the energy transition by enhancing reliability, flexibility, and security of the energy industry supply. Electrical energy storage is one of the main challenges for large-scale renewable power plants integration into the electric grid [42, 43]. The development of energy storage systems at different scales, with a satisfactory operation and answering to their specific demand characteristics, is needed to advance towards an electrified system with a high share of renewables [44-46]. Depending on the amount of energy stored, there are different types of energy storage systems. For small-scale energy storage the most advanced technology are electrochemical batteries characterized with a wide operating range, from minutes to several days [47, 48]. For large-scale energy storage are available: pumped hydroelectric power (the most widespread system, with large volume, long storage period and high efficiency, although limited to the availability of water reservoirs [49]) and compressed air energy storage systems (a commercially available technology, capable of providing large energy storage, with a long storage period, low capital cost and high efficiency, limited to dependence on favourable geological conditions [50]). There is also thermal energy storage [51, 52], with a wide range of applications, characterised by relatively low efficiency and low environmental impact [53, 54].

In the last years for storing electricity in thermal systems based on a combination of heat pumps and heat engines are gaining attention, so-called Carnot Batteries. They have been applied to energy storage in buildings, decreasing the energy demand of the system, increasing solar energy self-consumption, and minimising the installation cost [55, 56], charging a PCM system (using water) with air as the working fluid [57], or systems using CO_2 as the working fluid, based on conventional heat pumps [58], based on compression [58] or incorporating underground reservoirs, thermal or geological storage [59, 60].

In paper by Lanfranconi et al. [61] it has been shown that SLFB flow-cells with HDTMA as an anti-dendrite additive show a high cycle life of more than 7,000 cycles at 40 mA cm^{-2} with high efficiencies and without intervention to the system and therefore SLFB is a very promising candidate for energy storage applications. The work presented by Mabrouk et al. [62] presents a case report related to the management and the monitoring of a hybrid photovoltaic-wind system with battery energy storage, which the performance indexes are very simple and have been defined only with the purpose of showing the advantages of distributed generation. The aim of paper by DlzarAl kez et al. [63] is to evaluate the impacts of large-scale renewable power generation on power system dynamics from the perspective of the power system operator. The key finding is that rethinking in the development of grid code requirements and market mechanisms are needed if a power system based on 100% power electronic renewable generation is to be achieved. In paper by Hyun et al. [64], the optimization of the microgrid operation, the commitment of generators and the charging/discharging of ESSs, is formulated as a mixed-integer nonlinear programming

(MINLP) problem with inter-temporal constraints. The proposed method has a potential for facilitating full-scale parallel computation ability and the application to the real-time operation of microgrid system. In study by Khosravi et al. [65], an energy and economic analysis of a novel hybrid system with capacity 100 MW_e, based on a biomass/solar system equipped with a multi-effect desalination unit, is carried out. The results demonstrate that a solar thermal collector can be considered a promising solution to prevail the problem of the increasing boiler temperature. In paper Terfa et al. [66] present the research studies at laboratory to achieve building prototypes of smart distributed renewable energy micro-power plants in Africa, Fig 4. Four types of micro-power plants are being developed.

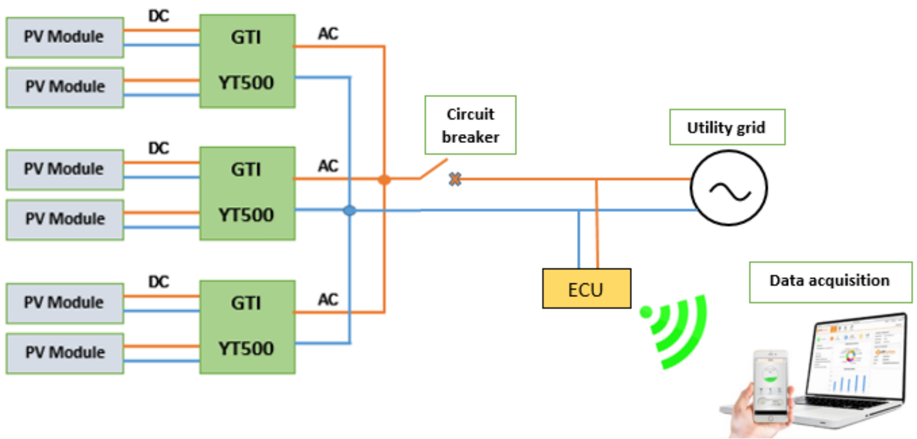

Fig. 4. Experimental structure of the PV Grid Tie Inverter micro power plant [66].

The purpose of paper by Stevovic et al. [67] is to make a research on solar power plants integration in an electric power system, taking into account all costs arising from circular economy criteria. The results show that the emissions and costs are higher without an introduced solar power plant. Introduction of solar capacities reduces the costs and emissions to a certain level. In paper by Carro et al. [68], a conceptual large-scale thermoelectrical energy storage system based on a transcritical CO_2 cycle is presented, Fig 5. The analysis shows the interest of the concept as a feasible integration for energy storage and CO_2 capture based on renewable energy, with an electric-to-electric efficiency varying between 40 and 50%.

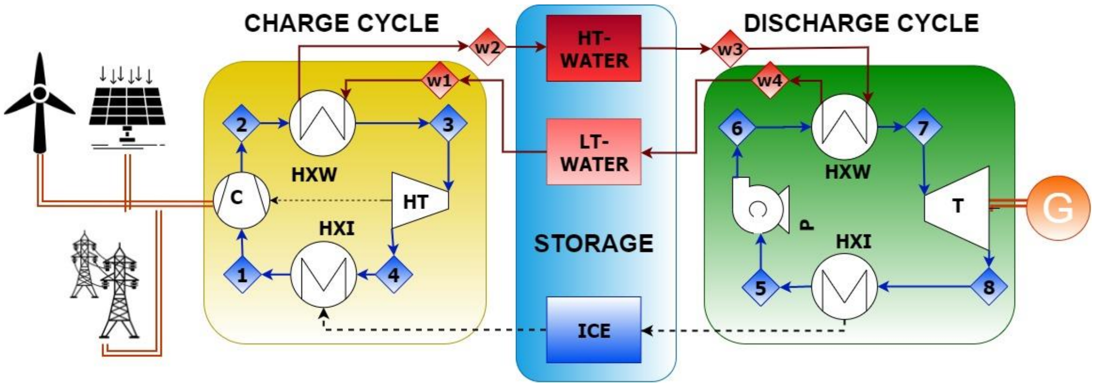

Figure5. Conceptual layout of the Thermoelectrical Energy Storage (ESS)-

C: Compressor; HT: Hydraulic turbine; P: Pump; T: Turbine; HXW: Heat exchange – Water;

HXI: Heat exchange – Ice; HT: High Temperature; LT: Low temperature [68].

The core objective of paper by Topalović et al. [69] is to investigate the cost-effectiveness of pumped hydro storage and large-scale battery storage systems. The major results of these investigations show the economic justification of pumped hydro storage systems implementation, their role in grid flexibility, and their influence on electricity market competitiveness.

2.4. Long term demand planning

Wind power technologies, as one of the popular renewable energies, have been advanced considerably and gained global attention [22]. With falling costs and large-scale production of generators, the deployment of wind energy is accelerating [70]. With such large increases in the deployment of wind energy, the power output forecasting of installed wind turbines is becoming vitally important, but it is a challenging problem [71].

Electrical power and energy flexibility is one of the key enablers of the distributed smart grid. Electrification is projected to double the quantity of electricity generation required by 2050 [72]. As a consequence, the quantity of renewable generation needed, even to maintain current integration levels, will be greater. In addition to current levels, renewable electricity integration targets are becoming increasingly ambitious [73-76]. Balancing the grid while hosting such high levels of renewable generation is a challenge for grid operators [77]. One of the mechanisms used by grid operators to address this challenge is power and energy flexibility on the demand side [78].

Active participation of electricity consumers in demand response (DR) may provide much needed flexibility to the energy system for integrating increasing shares of variable renewables [79]. The benefits of utilizing DR may be significant: 1) reducing load in critical peak hours can avoid costly capacity expansions and ease bottlenecks in distribution and transmission grids [80]; 2) remote activation of DR resources can provide ancillary services; 3) use of high marginal cost thermal generators is reduced [81]; 4) revenues for VRE producers increase and curtailment decreases [82]. Shifting consumption to off-peak periods can increase efficiency of thermal baseload plants through reduced cycling, and could help integrate renewables by absorbing overproduction.

Much attention in the literature on energy efficiency has focused on aggregate 'energy' use in the household and industrial sectors, with little attention paid to the supply of that energy and scant specific focus on the nature of, and interactions between, monetary and energy savings. The literature on the issue of 'rebound effects'has examined how energy savings from increased efficiency generate monetary savings that trigger (direct and indirect) demand responses that serve to erode the initial gains.

In the article by Tveten et al. [83] the models which describe availability of wind energy are utilized in analyses related to power system economics/policy, resource in simple statistical terms relevant to interactions of wind generation with electricity system, and electricity markets. Both properties are important for technical planning of future electricity systems, as well as rational design of policy measures. In the paper by Pfeifer et al. [84] is proposed that interconnections of a group of islands can be used to integrate the production from locally available renewable energy sources. The results showed that the interconnections increased the share of energy from renewable energy sources in the final energy consumption and declined the total critical excess electricity production, while vehicle to grid technology enabled exploitation of synergies between sectors. The paper by Leobner et al. [85] presents two different simulation-based concepts to integrate demand-response strategies into energy management systems in the customer domain of the Smart Grid (Model Predictive Control and Demand Side Management). While both approaches share a similar architecture, different modelling and simulation approaches were required by the use cases. The research by Spiegel [86] addresses the present situation on the German electricity market caused by variable renewable energy sources. The main finding of this research is a significant higher balancing energy demand with the expansion of photovoltaic and battery storage systems. The study performed by Kirkerud et al. [87] examines the future economic potential of demand response in the renewable rich northern European region (Norway and Sweden), and also analyses power markets impacts of large-scale demand response deployment in the region, Fig. 6. Results show that among the demand response options analysed, space heating and water heating provide the highest shares of loads shifted.

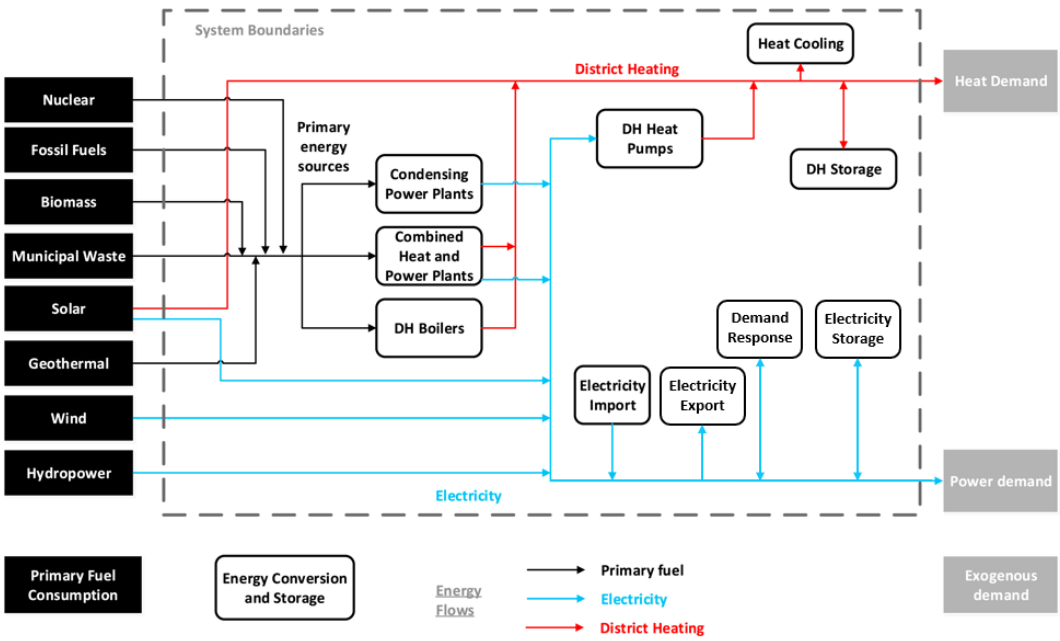

Fig. 6. BALMOREL core structure including demand response [87].

In paper O'Connell et al. [88] assess the quality of the services provided for demand response by analysing the results of experimental work activating flexible sources in buildings. The results show that fan data exhibits low uncertainty, suitable for ancillary services, whereas heat pumps' volatility is large.

2.5. Development of energy planning tools

Climate mitigation in urban areas has a crucial role in bending the curve of greenhouse gas emissions based on systematic structural and behavioural changes [89] while supporting flexibility in renewable energy systems [90]. In this context, a vital process remains ahead for enabling energy system actors to take the actions that are necessary to increase the pace of emission reductions with sufficient scale and timing [91]. Tools that can support the process of enabling cross-sectoral coordination and strengthening the policy making context of effective emission reductions can broaden and accelerate progress for climate mitigation, especially in urban areas where multiple opportunities are concentrated.

In recent years increases the need for new professionals in energy planning and several computational tools for energy planning have been developed. Ferrari et al. in [92] selected 17 tools targeted on an urban/districts scale that can evaluate several energy services, sources and/or technologies. Among them, 6 user-friendly tools were identified (energyPRO, HOMER, iHOGA, EnergyPLAN, SIREN, WebOpt) that can provide hourly energy calculations and can be considered as viable for widespread use.

Many studies and scientific papers have been published that consider the integration of renewable sources in energy systems, using the least-cost optimization models as a long-term generation expansion planning tool. Supplementary to these analyses, the paper by Taseska-Gjorgievska [93] focuses on the transmission network capacity for acceptance of variable renewable energy. In research work S. Kilkis [94] integrates the Sustainable Development of

Energy, Water and Environment Systems Index into a policy framework with three main components to compare possibilities for improving urban system performance, Fig. 7. The results have implications on considering urban system integration in the transition to net-zero targets, missions for climate-neutral cities, and the realization of 100% renewable energy systems.

Fig. 7. Summary of the framework of the research work with three main components [94].

Since, for wind power industries, designing an accurate and reliable wind power forecasting model is essential, Neshat et al. in [95] deployed a novel composite deep learning-based evolutionary approach for accurate forecasting of the power output in wind-turbine farms, Fig. 8. The achieved prediction results supported the superiority of the proposed hybrid model in terms of accurate forecasting and computational runtime compared with earlier published hybrid models applied in this paper.

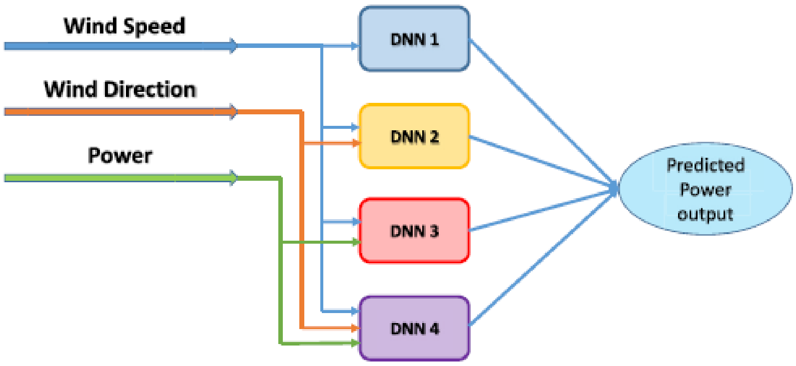

Fig. 8. The proposed four different independent forecasting models - the applied power as an input is the current generated power by the wind turbine [95].

As the country's economic objective is to ensure enough energy for its needs, many authors have attempted to determine the general empirical relationship between energy and the GDP, which could be a helpful tool in long-term national energy strategies [96]. The main scope of Koščak Kolin et al. research [97] was to develop and apply new methodology for energy prediction during a long-term period, based on the logarithmic relationship between electricity per capita and GDP per capita. The results show that energy growth in the first period was more than ten times faster in comparison to the following period, while financial growth was almost twice as large in the first period.

3. Energy savings in the building sector

Among all sectors, building one accounts alone for 40% of the total primary energy requirements in the European Union and it is responsible for 30% of greenhouse gas emissions. The development of effective energy efficiency strategies for buildings is thus crucial to tackle climate change toward the energy sustainable transition [98]. Energy in buildings is used primarily for space heating and cooling, ventilation, domestic hot water preparation and domestic appliances. The reduction of the energy consumption related to the mentioned building services can be achieved through various means, such as: i) the extensive use of renewables; ii) the energy efficiency improvement of standard systems [99], iii) the enhancement of the building thermophysics (e.g. adoption of innovative glazing systems, opaque elements and innovative technologies [100]), and/or iv) the adoption of smart energy management strategies [101-103].

Space heating and cooling dramatically affects the overall energy consumption of the buildings [104]. Considering the residential buildings, an average yearly specific consumption per unit floor area is around 180 kWh/m^2, including the energy consumption for lighting, appliances, space cooling/heating and domestic hot water [105]. Such high energy consumption can be justified by several factors, namely: high wall thermal transmittances, poor efficient of HVAC systems, loads for lighting [106] and appliances [107].

3.1. Knowledge of building energy demand

A recent solution lies in a new paradigm of energy management, which shifts from the supply-side to building demand-side control. The latter exploits the novel concept of building energy flexibility, that represents the ability of adapting energy consumption and storage operation without compromising technical and comfort constraints, to increase on-site renewable energy consumption, reduce costs and provide services to the grid (i.e. load shifting, peak shaving) [108]. Among the different strategies aimed at increasing grid stability arises demand response.

In investigation by Chung and Park [109], energy demand characteristics were surveyed and measured throughout Korea to establish load models for three types of buildings: hotels, hospitals, and offices. Substantial variations in the magnitudes and patterns were observed among the types of buildings and loads. The load models can be applied to a wide range of problems in building energy system design and planning, including simulations and optimizations of community energy systems. This paper by Koči et al. [110] reviews and discusses the coupled effects of warming trend in global mean surface temperatures, application of different design weather datasets, and utilization of different methods of building energy assessment on the calculated energy demands. The simulation results confirm the warming trend in the time period of 2013–2017 as the average heating demands are 3.95% lower and the average cooling demands 3.96% higher in a comparison with the Test Reference Year. The goal of study by D'Amico et al. [111] is to demonstrate that the assessment of building energy demand through the use of the degree day is correct only if the determination of the climate index is a function of the same weather data. The proposed methodology can be extended to any country and can be used to improve the reliability of any decision support tool based on climatic indexes. In research of Ferrari et al. [112] a survey of over 70 studies in scientific literature about energy profiles of buildings at the district level has been accomplished. As final results, tables summarizing the main methods characteristics and a selection of studies providing directly useable energy profiles are reported. In paper Calise et al. [113] propose a novel approach in order to accurately calculate the savings due to heat metering. Results show that in case of centralized heating systems equipped with thermostatic valves and heat metering devices, thermal energy savings up to 64% can be reached mainly when the system operates for many hours per day, leading to discounted pay back periods lower than 4 years.

3.2. Energy performance improvements of the existing buildings

The reduction of the energy consumption in new and already existing buildings is an important part in utilizing renewable energy [114]. Heat pump systems with various heat sources such as air, geothermal, solar thermal or wastewater are becoming increasingly important for the transition of energy, since renewable electricity can be used as their drive energy. To achieve an overall improvement in the household sector, domestic appliances such as washing machines, dishwashers, tumble dryers, refrigerators and freezers must also be considered. These represent a large percentage of the total energy consumption of a household. So, various approaches are being pursued to further improve the efficiency of domestic appliances: better insulated buildingsand, more efficient heating and ventilation [115, 116], reducing the amount of washing water for washing machines, improving insulation for refrigerators and freezers, etc. The greatest savings were achieved for tumble dryers by integrating a heat pump cycle [117].

The paper by Kovačić et al. [118] focuses on life-cycle based renovation strategies considering not only structural and thermal refurbishment, but also the social aspects of an ageing society needs, as well as a preservation of cultural heritage. In paper by Galatioto et al. [119], the state of the art of Italian residential building heritage has been reviewed, while energy retrofit issues and viable solutions have been investigated by collecting literature examples and experiences, focusing on common retrofit measures on historical buildings per thematic area. Virtič and Kovačič Lukman [120] introduce needs and solutions for capacity building in cross-border regions of Slovenia-Croatia-Hungary in order to better implement energy efficiency and renewable resources potentials. It was identified that a lack of knowledge by the stakeholders represents a main obstacle for implementing more environmental and economic acceptable energy solutions on a local and regional levels.

In investigtions by Fořt et al. [121], a quantification of physical, social, economic, and environmental benefits resulting from the application of exterior thermal insulation system to an institutional building is presented. Full investments recovery rate varying from 43 to 60 years in dependence on applied economic scenarios reaches almost the lifetime of used materials. Ayikoe Tettey et al. [122] analyse final and primary energy savings and overheating risk of deep energy renovation of a Swedish multi-storey residential building of the 1970s under climate change and consider overheating control measures to reduce cooling demand and risk of overheating. The total operation final and primary energy use decrease averagely by 58% and 54%, respectively when all the measures are cumulatively applied under both current and future climate scenarios. In research by Caputo et al. [123] is focus on the renovation of two historical buildings within the farmhouse. The application of the proposed method to the mentioned case study can support in tackling the challenges of protected buildings energy retrofit. Frank et al. in paper [124] present an innovative system concept in which domestic appliances are thermally connected to the heating and ventilation system via the energiBUS, using a heat pump as the central heating and cooling device. The system benefits from the replacement of internal heating and cooling devices of the respective domestic appliances and the simultaneous utilization of both energy flows - warm and cold - of the heat pump. The paper by Pinto et al. [125] explores the opportunity to enhance energy flexibility of a cluster of buildings, taking advantage from the mutual collaboration between single buildings by pursuing a coordinated approach in energy management. Results shows a reduction of operational costs of about 4%, together with a decrease of peak demand up to 12%.

3.3. Building envelope

Building envelope is the most responsible architectural element of the building that impacts thermal comfort and energy balance. From the design point of view, the analysis of various facade scenarios, in terms of their contribution to reducing energy consumption, is crucial and necessary for each specific case and climate. Although solar harvesting in buildings dates back to earliest times, its use depends on natural constraints which forced humans to exploit fossil fuels to cover additional needs, particularly heating, cooking and night lighting. The rediscovery of some of this knowledge was stimulated by the solar architecture movement, triggered by the oil crisis of the 1970s. Renewable energy harvesting should be examined from various angles which may be “passive”, “active” or hybrid, to optimize and diversify sustainable technologies. Of the known passive heating solutions for buildings, the Trombewall is one of the earliest notorious bioclimatic strategies [126].

On the case study by Kovačić et al. [127] of an energy efficient industrial facility, a decision-support tool was developed for analysing life cycle economic and environmental impacts of facade-systems, which has large implementation potential as a relatively easily applicable decision-support instrument. In paper by Visa et al. [128] a novel type of facade, flat plate - small sized solar thermal collector, with triangle shape was developed. Based on the simulation results, three collectors (with black, green and orange absorber plates) were manufactured; efficiencies of 55%, 42% and 35% were obtained on the indoor testing rig.

The paper by Krstić-Furundžić et al. [129] presents the estimation of energy performances of different scenarios of the hypothetical models of façade design, in case of an office building in Belgrade climate conditions. The various alternatives of shadings contribute to the reduction of total energy demands, and the application of shadings reduces of environmental pollution. Study by Pučko et al. [130] presents a new approach to automated/semi-automated comprehensive energy and the whole life-cycle cost analysis of building envelope components. In summary, the main contribution of this approach is provision of a comprehensive and simple insight into all costs in a transparent way.

Study by Simoes et al. [131] set out to assess how subtypes of the Mediterranean climate would affect the energy performance of Solar and Trombe walls envelope systems, Fig. 9. The results demonstrate that solar and Trombe walls can both lead to significant reductions in net energy demands if properly tailored shading devices and vents with specific seasonal and daily operation schedules are implemented.

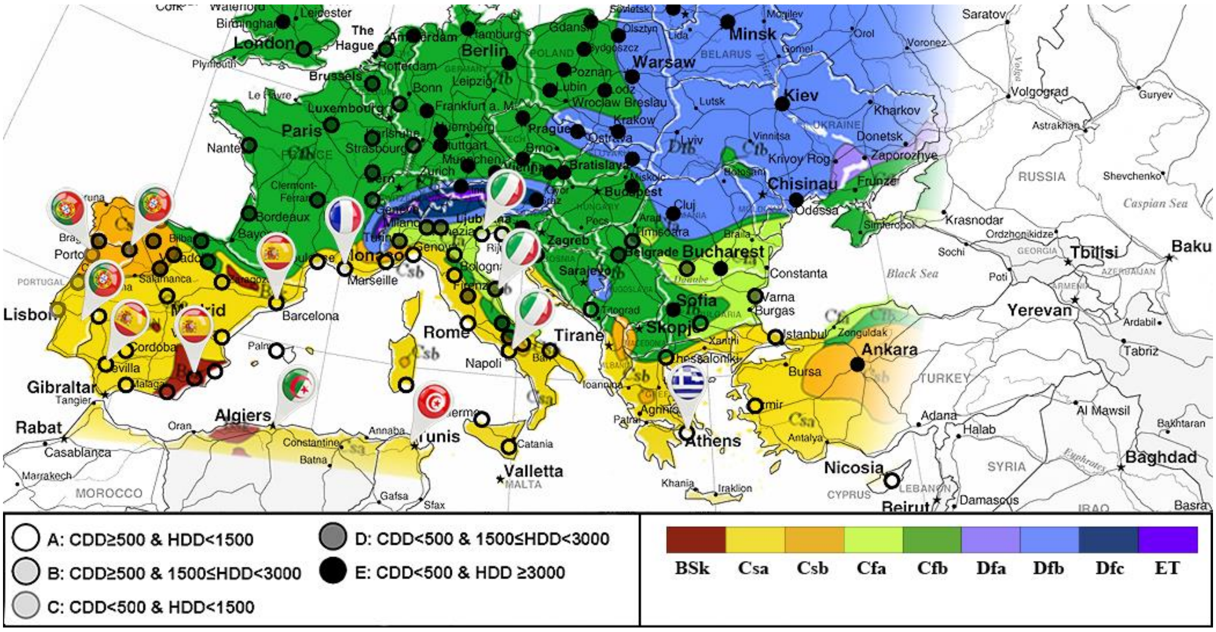

Fig. 9. Geographical distribution of selected cities and their classification into climatic zones on the basis of the CDD/HDD approach and vegetation-based empirical K€oppen-Geiger climate classification. BSk: Arid, steppe, cold desert; Csa: warm temperate, hot dry summer; Csb: warm temperate, warm dry summer; Cfa: warm temperate, fully humid, hot summer; Cfb: warm temperate, fully humid, warm summer [131].

Barone et al. in paper [132] present an innovative Concentrating Photovoltaic Glazing system to be adopted in smart building façades (CoPVG), Fig. 10. By using the novel façade system, interesting energy savings ranging from 30 to 60% for the investigated weather zones can be obtained.

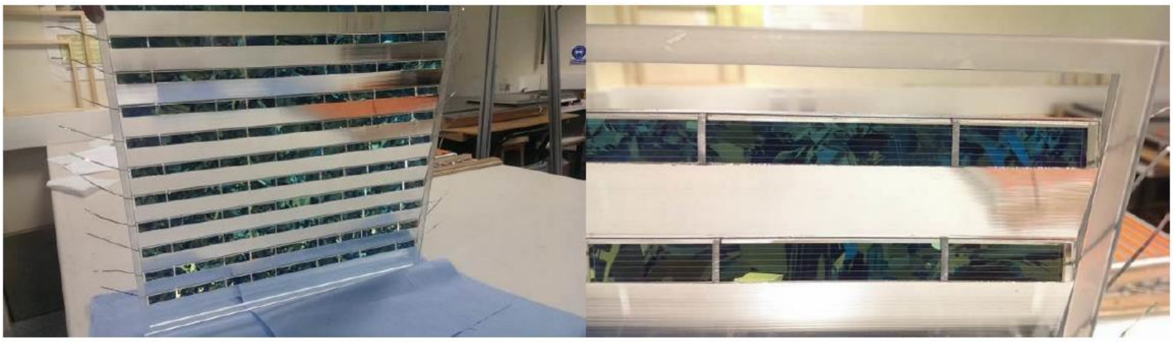

Fig. 10. The CoPVTG: concentrating glass lens with PV/T absorber elements [132].

District heating

District heating and cooling systems are convenient and highly efficient solutions to move towards zero energy cities [133], particularly in areas with high population density. By leveraging low-grade and sustainable energy sources, these systems lead to substantial primary energy reductions for space heating and domestic hot water production resulting in a technology for potential emission reduction [134].

Currently, high-efficiency thermal plants, such as combined heat and power plants (CHP), are typically installed in district heating systems to supply the base load [135]. The occurrence of thermal peaks represents a crucial issue in district heating applications since they lead to an overall reduction of the system efficiency [136] and undesirable increases in the mass-flow rates circulating in the network [137]. The identification of different strategies to cut the peaks (and fill the valleys) is attracting ever-growing interest in the recent literature. Among the different possibilities for shaving the peaks, an interesting option consists in the adoption of Thermal Energy Storages (TES).

A different possibility for thermal peak shaving is represented by “virtual storage” [138], which is obtained through modification of the heating load of some of the buildings connected to the district heating network. Thus, “virtual storage” is a Demand-Side Management (DSM) technique that exploits the flexibility and the active role of the consumers in order to tailor the demand to the usability of the production and to increase the overall efficiency of the system [139].

Also, the two different strategies for peak shaving (i.e. physical thermal storages and demand-side management) can be simultaneously adopted to improve the performances of district heating networks: the effects of TES and DSM are not overlapping, but complementary for the system perspective [140].

Another important aspect that is worth to take into account when dealing with optimization of district heating systems is represented by the increasing evolution towards smart energy systems [141], including heating, cooling, electricity, and gas grids [142].

In paper Hast et al. [143], district heating scenarios towards carbon neutral district heat production in 2050 were formed for Helsinki region, Warsaw and Kaunas based on the plans and goals of the studied cities and the companies supplying district heat in these regions. It was found that increased use of biomass and waste as well as utilization of geothermal and waste heat could be expected in the studied regions in the future.

The effects of new heat pump and solar collector capacity in an existing district heating system are investigated by using Helsinki as a case study performed by Rämä and Wahlroos [144]. Existing heat supply consists of combined heat and power plants, boilers and large-scale heat pumps. Also, the potential benefit of low distribution temperatures is evaluated. Low temperature distribution improves the performance of the system by 4 % in both costs and as emission reductions compared to normal distribution temperatures.

In paper by Rosato et al. [145] a centralized hybrid renewable district heating system based on the exploitation of solar energy and integrated with a seasonal borehole thermal energy storage is investigated. The simulation results obtained by Von Rhein et al. [146] quantify the performance of the fifth-generation of district heating and cooling network based on various output metrics, including primary energy usage, carbon dioxide emissions, and network implementation cost. Using multi-objective optimization, research in Dorotić et al. [147] shows that for equal level of carbon dioxide emissions, combined district heating and cooling systems have lower total discounted cost when compared to district heating and cooling systems which operate separately.

The research by Caputo et al. [148] aims to evaluate the technical features and the performance of a large sample of biomass district heating plants (BDHP) fuelled by wooden chips. Paper by Pieper et al. [149] reports a study on how hourly temperature variations of different heat sources influence the seasonal coefficient of performance (SCOP) of heat pumps (HPs) when supplying district heating. The results indicate that a maximum system performance may be achieved for HPs based on a combination of different heat sources. Thermochemical energy storage provides opportunities for pressure-less and low-loss seasonal storage at high energy densities. The paper by Böhm et al. [150] supports a pre-selection of relevant thermochemical materials and applications in district heating for future detailed analysis. Paper by Kazagić et al. [151] elaborates the concept of the renewable district heating system (DHS) in Municipality of Visoko, Bosnia and Herzegovina, as part of the CoolHeating project, which is going to be integrated into the planned DHS supplied by a combined heat and power facility (CHP). The case of a new nearly zero-energy district, located in the Milan urban area (Italy), in paper by Aste et al. [152] is presented. The obtained outcomes prove the benefits of the combination of a wood biomass CHP with GWHPs and PV with a significant share of renewable energies. Work by Capone et al. [153] proposes an innovative optimization approach that can be applied to energy systems composed by multiple small units for the production and conversion of electricity, heating and cooling. Results show that thermal storage installation can reduce costs of about 1.5%, while its integration with demand-side management leads to a cost reduction up to 4% and allows reducing the storage size. The goal of paper by Hiltunen and Syri [154] is to simulate the impacts of replacing heat demand with combined heat and power units with renewable fuels, heat pumps and waste heat utilisation on the production costs and CO_2 emissions of the Espoo district heating system. The results show that abandoning coal in the city's heating system leads to a significant reduction of CO_2 emissions with a small increase of annual production costs. As a method presented in paper by B. Kilkis [155], the Rational Exergy Management Model (REMM) derived fourteen metrics, aiming to minimize the CO_2 emissions responsibility, Fig. 11. The paper concludes that low-temperature heating either in district energy systems, in private buildings, or prosumers is both environmentally, economically, and technically feasible.

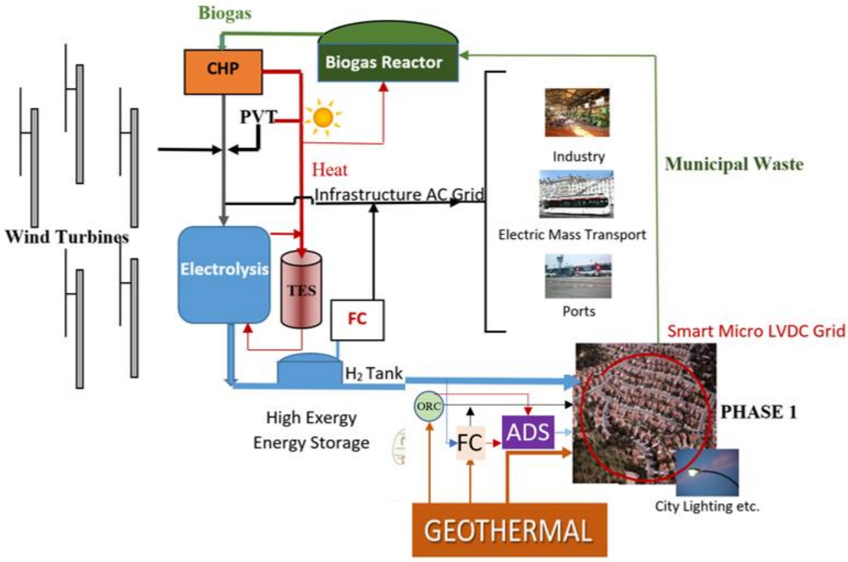

Fig. 11. Hydrogen City (HC) Concept for a New Settlement for China [94].

In work by Zirngast et al. [156], an improved method for the Mixed Integer Nonlinear Programming (MINLP) synthesis of flexible Heat Exchanger Network with a large number of uncertain parameters is presented. The synthesis of the heat exchanger network shows that the implementation of correction factors improves the optimal result by 7.6%.

Electrification of transport

The development of transportation systems plays a crucial role in a modern society facing population growth issues with a challenging mobility demand. Despite the notable advantages of transportation development, certain disadvantages have burst as well. For instance, conventional transportation systems based on direct combustion represent the second-highest contributor to greenhouse gases (GHG) and polluting agents emissions into the atmosphere [157]. In the EU, approximately 30% of fossil fuel emissions come from the transportation sector [158]. Moreover, in recent decades, this sector exhibited the highest GHG emissions growth, accounting for 24% of total emissions in Europe [159]. Within the category of quantity-based climate change mitigation mechanisms, the limitation of the increase of global temperature can be achieved by the electrification of at least 20% of the transportation systems by 2030, reaching ecological balance [160]. EVs' introduction represents a promising alternative to support the decarburization goal, improve urban air quality [161]. Moreover, Evs enhance energy security and efficiency since ICEVs motors' efficiency is 28-30%, while EVs motors reach 85-95% [158]. Similarly, EVs exhibit great potential in environmental protection, with a decrease in net GHG emissions accounting for 28%-67% compared to the ICEVs [162]. Nevertheless, the impact of EVs' utilization is highly dependent on the electricity generation mix for charging the EVs batteries [158]. Incorporation of renewable energy sources in to the overall transportation energy mix, such as base-level hydroelectric power [163], as along with the more intermittent but still abundant wind and solar (photovoltaic) energy sources can further offset the greenhouse gases emissions and reduce air pollution [164].

World is faced with roll out of the commercial generation hydrogen fuel cell electric vehicles on the road. Anticipating estimated development there is a question when and how will Croatia keep along with this global scenario? One of the possible answers, derived from Croatia position as EU country that draws 13% of its GDP mostly from tourists flooding during two summer months, was discussed in paper by Firak and Đukić [165]. In paper by Dominiković et al. [166] a detailed literature review was carried out in order to detect the current state of the research on clean transport sector, as well as to point out the gaps in the research. Results showed that 72.3% of the transport energy demand on the EU level could be directly electrified by the technology existing today. The principal motivation of work by De Souza et al. [167] is to evaluate the existing fuel use (gasoline or ethanol) and new alternative source of power supply (electricity) for vehicles in Brazil, and to assess potential to consume less petroleum and nonrenewable fuels, in order to reduce the air pollution and greenhouse gas emissions. In study by Bellocchi et al. [168], the impact of electrification of both private transport and space heating is assessed for the Italian energy system. Results confirm that both transport and heating electrification can lead to significant reductions in CO_2 emissions, around 25-30% if pursued independently.

To improve life quality in urban areas it is very important to reduce noise level and consumption of fossil fuels, which pose significant risks to the health. There is an urgent need to increase use of alternative fuels and alternative automotive powertrains in mobility applications and to switch from car-oriented mobility toward public transport. Mass public transport is the backbone of urban mobility, especially in large cities with high population density. Bus is dominant transport mode with a 63% share (diesel buses represent 50% of all bus fleets where 22% of the buses use diesel in combination with biodiesel or some other additives). Different types of electric busses account about 18% of all buses [169, 170]. Many cities worldwide have enforced the development of city buses using alternative propulsion systems, the transition towards zero-emissions city buses, such as battery electric buses and fuel cells buses.

The goal of paper by Ajanović et al. [171] is to analyse prospects and barriers for fuel cell buses focusing on their economic, technical, and environmental performance. Results show that the prices of fuel cell buses, although decreasing over time, are still about 40% higher than those of diesel buses and the it is major barrier, for a faster penetration of fuel cell buses, Fig. 12.

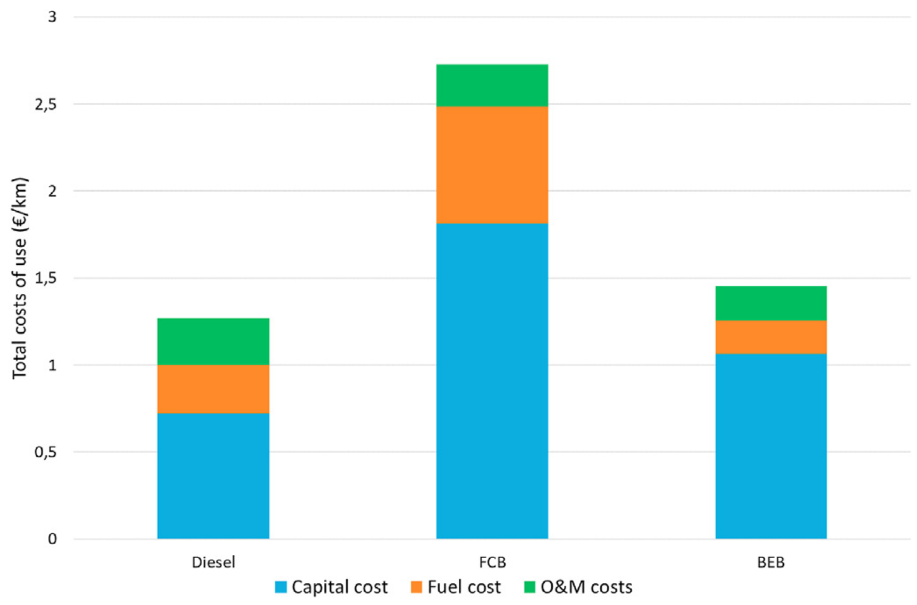

Fig. 12. Total cost of use of diesel-, fuel cell- and battery electric busses, 2018 [171].

According to public opinion, the railway transportation system exhibits more environmental-friendly aspects considering its independence of fossil fuels [172]. However, this opinion may be biased since, worldwide, approximately 30% of the total railway lines are electrified, ignoring the emissions repositioned from the power plants responsible for the energy supply [173]. For instance, electrical transportation systems energized by renewable energy sources (RES) promote the shift from conventional electrification to a post-carbon infrastructure given the utilization of efficient technologies for power supply [174]. On the other hand, fuel cells (FC) display great potential for clean transport systems, for which hydrogen as a zero-emitter fuel would become a viable alternative in the transport sector [175].

Study by Loy-Benitez et al. [176] proposes energy system consists of a proton-exchange membrane electrolyzer, solid-oxide fuel cell, and lithium-bromide absorption chiller assisted with solar radiation and wind turbine to simultaneously generate power, hydrogen, cooling, and heating loads, Fig. 13a. A novel approach consists of power-pinch analysis and multicriteria decision-making (MCDM) to determine the optimal sizing of renewable resources considering the system's thermodynamic, economic, and exergy performance, Fig. 13b.

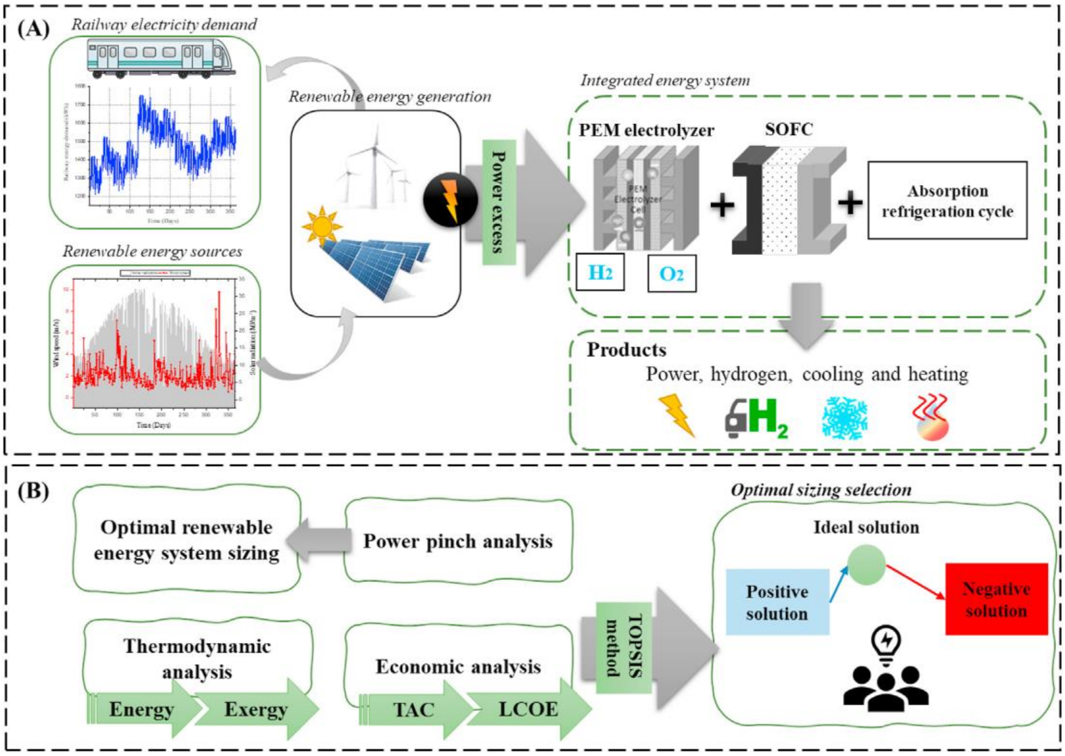

Fig. 13. A framework of the presented study: (a) design of the integrated system for railway electrification demand and subproducts generation; and (b) smart management and techno-economic assessment [176].

Also over railway lines, especially lengthy and characterized by low traffic densities, which are still not electrified due to significant capital infrastructure costs [177], battery electric locomotives are also capable to operate [178]. Introduction of energy storage technologies into the railway transport has also indicated significant potential to improve its energy efficiency [179]. Alternative energy storage technologies suitable for railway vehicle hybridization have also been considered: flywheels [180], hydrostatic energy storage systems [181], without and with ultracapacitors as auxiliary power sources [182], and battery-ultracapacitor hybrid energy storage systems [183].

Cipek et al. in paper [184] consider a novel approach to heavy-haul of railway freight by means of combined operation of conventional diesel-electric and battery-electric locomotives either in single or joint (tandem) operation. The results show that between 22% and 30% fuel cost savings may be achieved, along with reduced emissions of exhaust gases by using the proposed battery-electric locomotive in combination (tandem) with the conventional diesel-electric one.

However, there are still several challenges that need to be addressed to favour the spread of electric cars. From these challenges the most important are the battery capacity, the price of the cell and the battery lifespan [185]. Another important issue for electric vehicles is represented by the battery recharge time [186]. Battery cells temperature management is connected to all these problems, since temperature inhomogeneity and high operation temperature reduce cells performance and thus make batteries less reliable and economically convenient [187].

In work by Perez Estevez et al. [188], an electro-thermal model of a single lithium-ion battery cell has been developed. This model can be used as a tool to define new modules architecture, as well as to support the design of the battery cooling system.

Water- Energy Nexus

Extracting, delivering, and disposing water requires energy, and similarly, many processes for extracting and refining various fuel sources and producing electricity use water [189]. This connection is called ‘water-energy nexus’ and it is important to understand due to increasing energy demands and decreasing freshwater supplies in many regions. Currently, a large amounts of water are used in hydropower generation, and thermal power plants require water for cooling purposes. Water constraints, droughts, heatwaves and temperature rise of river water have already compromised power generation in Europe [190-192]. The researchers note that without a radical improvement of the water resource management in the power sector, the power plants' demand for water might surge considerably in the future [193]. In general, renewable energy technologies (solar PV and wind generation) are known to consume considerably less water compared to conventional fossil-nuclear fuelled power plants but other as for instance, hydropower and bioenergy could consume water more intensively than the fossil-based systems they replace [194, 195]. Thus, a more careful assessment of energy-based water consumption will add another layer in the discussion of the sustainability of 100% renewable energy systems [196-199]. In the annual report released by theWorld Economic Forum [200], "water crisis" is listed in the top-10 global risks in terms of both likelihood and impact for the year 2020. Thus, solutions to the global water security and scarcity crisis must involve water-energy nexus approaches for harmonizing policies and strategies that deal with these inter-related sectors with a main goal of minimizing the environmental impact and maximizing the human benefits [201].

In the paper by Schlör et al. [202] the integrated assessment model is used to frame and study the heterogeneity of the food-energy-water nexus and to manage the food-energy-water nexus in Germany in a social learning and decision-making process. It is found that the new food-energy-water nexus policy process also needs a „culture of reflected numbers".

In paper by Lohrmann et al. [203] an energy-system-wide analysis of water demand in Europe was performed for the period 2015-2050 using the LUT Energy System Transition model for two scenarios: Area (with electricity interconnections) and Regions (without). For fossil-fuelled power plants, the water footprint in 20 European regions may decrease considerably until 2050, by 28.3% in the 'Area scenario' and 24.2% in the 'Regions scenario', Fig. 14.

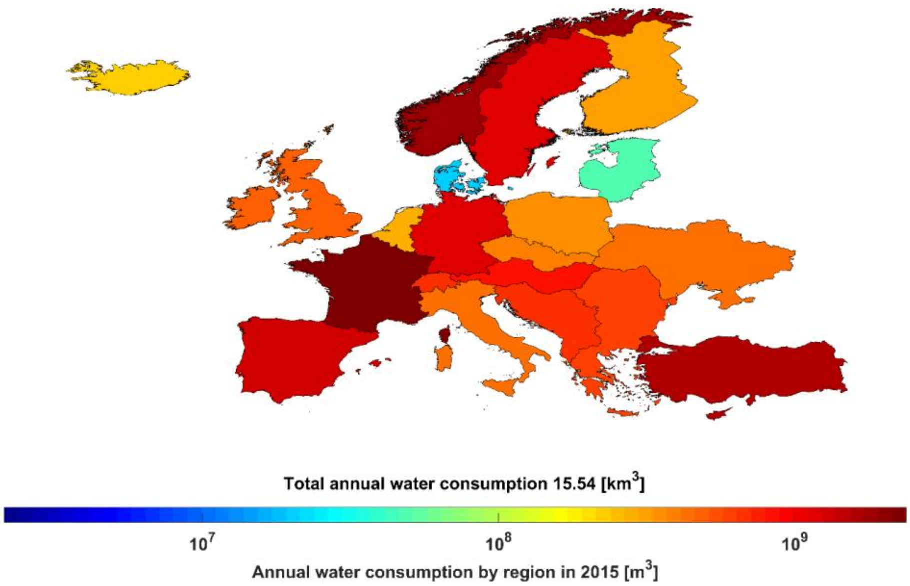

Fig. 14. Total water consumption (median values) of the Europe's power sector in 2015, in m^3 [204].

Paper by Pavičević et al. [204] describes a new modelling framework for analysing the water-energy nexus in the African Power Pools, Fig. 15. The results show a good agreement between the model outputs and the historical values, despite data-related limitations. It appears that some African power pools heavily rely on the availability of freshwater resources, while others are less dependent.

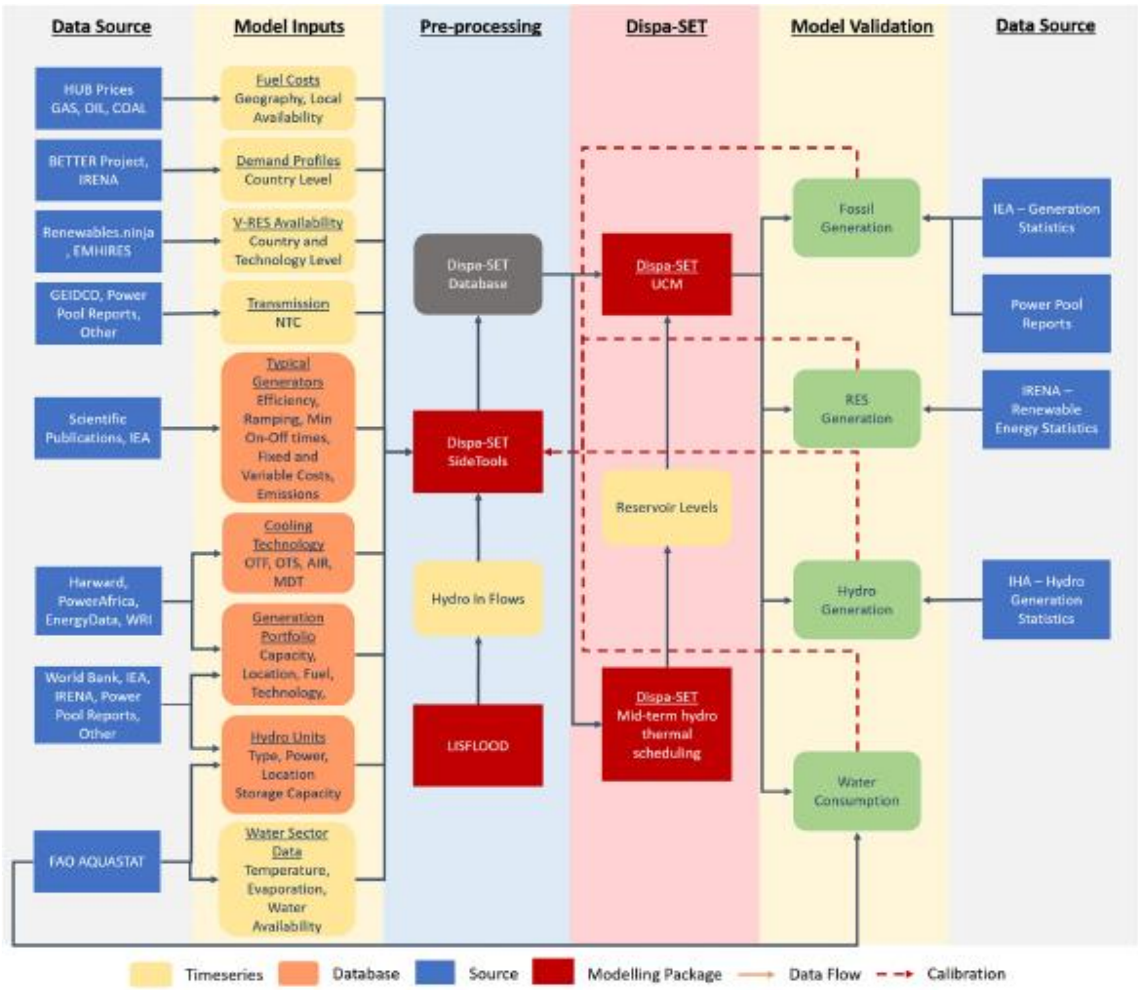

Fig. 15. Flow chart visualizing the different steps for the modelling framework within study in [204].

Conclusion

This review paper as part of special issue of Energy, dedicated to the SDEWES Conferences held in 2020, 2nd Latin American SDEWES Conference - Buenos Aires, Argentina, 1st Asia Pacific SDEWES Conference, Gold Coast, Australia, 4th South East Europe SDEWES Conference, Sarajevo, Bosnia and Herzegovina) and 15th SDEWES Conference, Cologne, Germany, presents recent advances in several main fields that are important to the sustainable development of energy, water and environment systems: energy system analysis, energy savings in the building sector, district heating - integrated heating, cooling and electricity systems, electrification of transport and water-energy nexus. Sustainable energy policy, development of energy planning tools, long term demand planning and management are mandatorily needed to achieve smart energy systems, specially smart island energy systems, high penetration of renewables – to 100% renewable energy systemes in which energy storage systems could play a crucial role in the energy transition by enhancing reliability, flexibility and security of the energy supply. The development of effective energy efficiency strategies for buildings is crucial to tackle climate change toward the energy sustainable transition and the reduction of energy consumption in this sector is very important. To this scope, several actions are required, such as knowledge of building energy demand, energy performance improvements of the existing buildings and building envelope. District heating with integrated heating, cooling and electricity systems, with a high renewable energy penetration, are convenient and highly efficient solutions to move towards zero energy cities, particularly in areas with high population density. Transportation systems plays a crucial role in a modern society facing population growth issues with a challenging mobility demand. Unfortunately, conventional transportation systems based on direct combustion represent the second-highest contributor to greenhouse gases (GHG) and polluting agents emissions into the atmosphere. So, electrification of transport represents a promising alternative to support the decarburization goal, improve urban air quality. „Water-energy nexus“, which is the connection between the energy required for extracting, delivering and disposing of water and the water required for extracting and refining various fuel sources and producing electricity, is important to understand due to increasing energy demands and decreasing freshwater supplies in many regions. From the papers published in the five hot topics, it is clear that although the field of sustainable development is multidisciplinary, an integrated approach is needed. Such an approach is offered by SDEWES Conferences, as a meeting place of scientists and experts, and for the exchange, dissemination, and promotion of new ideas. The quality of research presented in this special issue and previously published in past SDEWES special issues suggests that the SDEWES conference will continue to be a generator of development of new methods, policies and technologies for both efficient production of energy, mainly from renewable sources, and consumption in industry, buildings and transport, water use and environment protection. On this way SDEWES Conferences foster sustainable development and the transition to a low-carbon society, to achieving the goals of the Paris Agreement, which is a big challenge after COP-26 which which by acceptance "phase down" instead "phase out" prolongs the coal era.

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