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Review

Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management

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ABSTRACT

The role of smart technologies can become very important and useful to solve the main population issues nowadays and provide foundations for a sustainable future. A smart approach is an opportunity for knowledge integration, necessary to solve crucial problems of contemporary societies. Today, the main challenge is to reduce the effects of global warming and ensure a balanced economic development of society. The close collaboration of all involved engineering professions is mandatory to achieve interdisciplinary synergies and can bridge challenging engineering tasks. Intense research efforts should be directed towards balanced resource utilization, efficient energy conversion technologies, integration of renewable energy systems, effective approaches to enable circular economy framework, effective process integration as well as other issues important to the population. This review editorial is primarily focused on the contributions presented at the 3rd International Conference on Smart and Sustainable Technologies held in Split, Croatia, in 2018 (SpliTech2018). The SpliTech2018 conference was a multidisciplinary event with research topics related to the main conference tracks, i.e. Smart City/Environment, Energy, Engineering Modelling and e-Health. The strategic focus of the conference was to help solve crucial issues of our times, mainly related to the sustainability and smart utilisation of limited and valuable resources. This contribution brings new ideas and discusses present issues as well as challenges that should lead towards a sustainable future based on the application of the smart technologies. The herein addressed papers bring together latest research progress into four main topic areas: (i) Green Buildings, Energy Use and Consumption, (ii) Solar Energy Utilisation, (iii) Efficiency and Waste Elimination, (iv) Smart Cities and Internet of Things. The main results of this introduction review article include a discussion of different concepts and technologies that bring further development on a broad range of topics focused on efficiency improvement, smart and sustainable resource management, cleaner production concepts and on the discussion of the various actions which would lead towards a sustainable future.

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1. Introduction

1.1. The call for sustainability

Global greenhouse gas emissions are continuously growing on a global scale, Fig. 1 (Pbl.nl, 2018), where climate change issues are ever more present, causing severe impacts to the population (Xu et al., 2019a). Dominant emissions are ones related to CO_2 and 2018 was a record year of some sort since CO_2 emissions increased by about 2.7%, while in 2017 the increase was 1.6% (Globalcarbonproject, 2018). This recent trend in CO_2 emissions is obviously concerning (Fig. 2), especially when knowing that the CO_2 level was almost stable (IEA, 2017) in the period from 2015 to 2017. The present CO_2 level is more than 411 ppm (co2.earth, 2019), while for instance, it was below 400 ppm just five years ago. The more severe GHG is methane (CH_4), since it is almost 30 times more potent as a heat-trapping gas when compared to CO_2, (sciencedaily, 2014). Relatively large quantities of the CH4 are being trapped in the ice sheets that are gradually released in the atmosphere by melting of the ice sheets due to climate change issues. The Paris climate agreement in 2016 by UNFCCC (United Nations b, 2018) was an important step for addressing this problem since policy makers showed a willingness to gather global efforts to combat climate change issues and to limit warming below 2 °C. It is more than clear that present actions are not sufficient and that resolute and timely actions are needed on a global scale to be able to achieve this goal and hence to reduce the harmful impacts of anthropogenic activities on the environment, (Wang et al., 2019a). In this line of approach, it is the necessity for sustainable development, which leads to the integration of efficient approaches that are based on the multidisciplinary knowledge, (Baleta et al., 2019).

Besides concerning the rise of CO_2 emissions, there is also a constant rise of other harmful pollutants such as N_2O emissions, CH_4 emissions, due to livestock, rice production, natural gas and oil production, synthetic fertilisers etc.

The general impact of population on the environment is obviously a complex one: problems related to plastic waste have become more severe lately, since there is strong evidence of their long-term unfavourable impacts on sensitive ecosystems, which is already monitored in the form of micro-plastic polluted oceans, with direct impact on the human food chain, Fig. 3 (Prata et al., 2019). In the case of the EU region, plastic waste is quite a serious issue, since the yearly quantity produced ranges from 10 kg per person to over 40 kg per person, with an EU average of about 31 kg per person, (Weforum, 2018). The main region which is critical with respect to the plastic waste issue is North Pacific, Fig. 3. Timely, targeted and efficient efforts are needed to prevent further plastic pollution (Ferreira, et al., 2019)

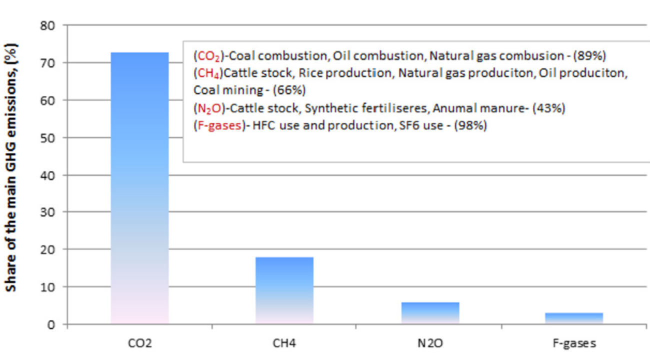

Fig. 1. Global greenhouse gas emissions, (Pbl.nl, 2018).

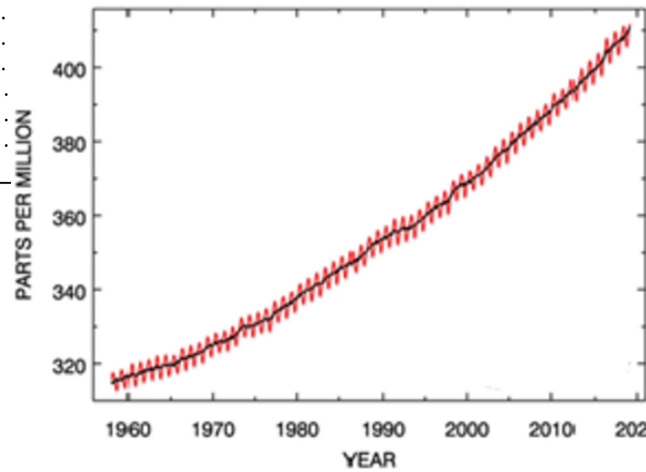

Fig. 2. CO_2 emission trend, (Noaa, 2019)

The major challenge related to the issue of plasticscould become truly pressing by 2030 when China plans to ban the import of plastic waste, as China has been importing about 45% of the world's overall plastic waste since 1992 (cbc.ca, 2018). Joint efforts are needed, both technological and social; countries need to be able to adopt and shift from a "plastic based society", i.e. drastic changes in habits and perception would be required, (Nielsen et al., 2019).

Plastic pollution is one of the greatest challenges related to waste issues, but one of the major issues is the food waste problem (as well as food lost in production processes), which becomes increasingly emphasized by the general rise of the population that is mainly concentrated in cities. According to data from 2015, the annual global quantity of food waste ranges from about 95 to 115 kg/consumer in developed countries (data with excluded quantity of food waste from production processes), while 6–11 kg/consumer is expected to be waste annually in less developed parts of the world (Weforum, 2015), Fig. 4.

Food waste has a significant impact on sustainability and environment being currently accountable for more than 3 Gt/y of CO_2 emissions. It is estimated that about 28% of the worlds' agriculture area is already "utilized" for the production of wasted food. Once more, as it is being the case with plastic pollution, one of the mandatory goals is to raise public awareness, regarding food waste issue (Ellison et al., 2019) and to ensure technological advances to support and enable a food waste reduction (Principato et al., 2019).

1.2. The energy sector

Coming to the energy sector, present electricity production globally is still based to a large extent on fossil fuels, i.e. by more than 50% (Fig. 5 data based on IEA electricity information), mainly coal and natural gas. One of the main issues with existing fossil fuels energy systems is their conversion efficiency, which is relatively low, with a high rate of wasted thermal energy.

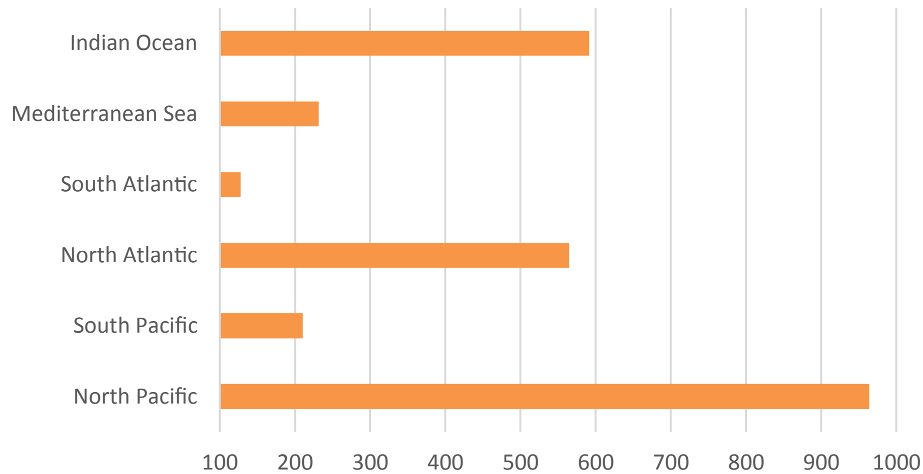

Fig. 3. Global distribution of plastic waste in World's Oceans in thousands of tons, (Weforum, 2018).

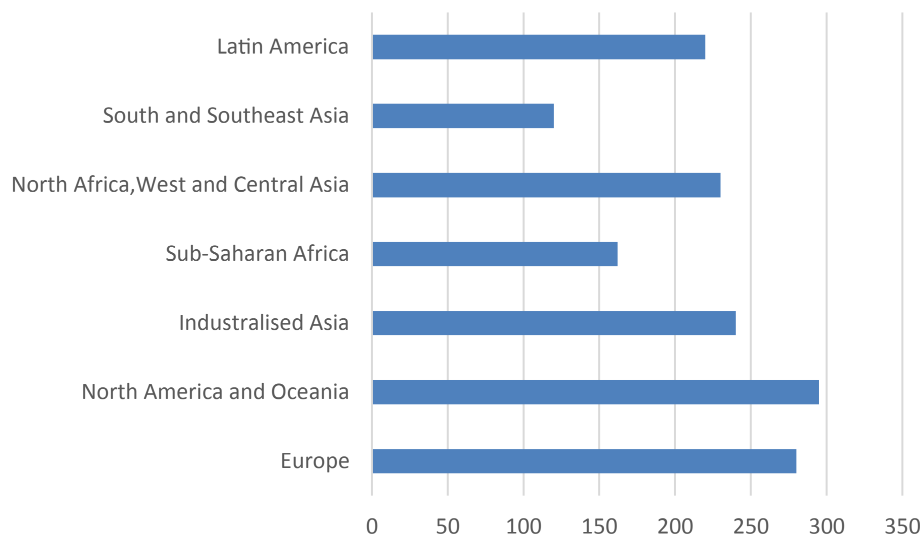

Fig. 4. Food losses and food waste per countries in kg/y, (Weforum, 2015).

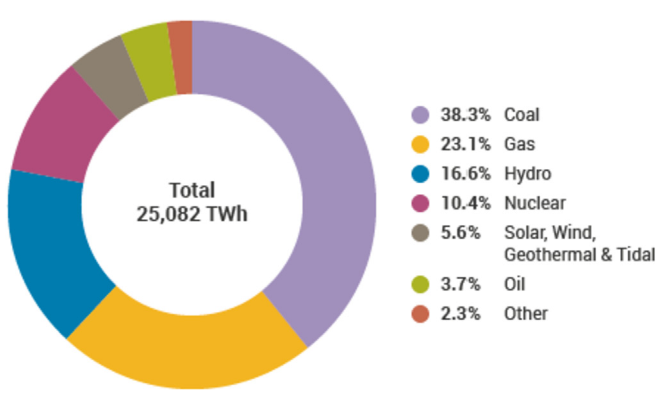

Fig. 5. Global electricity production from sources in 2016 (World-nuclear, 2019),

For coal-based power plants, it is reasonable to expect average energy conversion efficiency from 35% to 45%, the latter value for state-of-the-art plants, while for natural gas the efficiency can go up to 60% for combined cycle plants (worldenergy, 2014). Consequently, the operation of current fossil fuels based technologies is followed with a high rate of released waste heat, about 60%–70% on average, and which by large is not properly utilised. The novel, i.e. more efficient energy concepts are necessary to provide more efficient utilisation of released waste heat, especially in industrial applications, (Brückner et al., 2015). The magnitude of total rejected energy is caused due to the limitations of the electricity generation technologies and the transmission and distribution of electricity (Flowcharts, 2019). Besides the development of cleaner transportation systems, (such as electric driven vehicles or even novel alternative transportation systems), more efficient engineering solutions are needed in the case of fossil-based engines with internal combustion, which one can reasonably expect that will continue to dominate the automotive market in the close future. The global picture regarding transportation is starting to change, especially in terms of globally sold electric cars, albeit at a slow pace, Fig. 6, (Reuters, 2018). China is planning to produce more than 600,000 electric buses by 2020, (sierraclub, 2018), so expected rise in the number of electric vehicles is almost exponential one.

Some countries have announced their will to ban diesel vehicles, especially equipped with older than Euro 4 norm diesel engine versions, (Reuters, 2018) and this decision already influenced the declined sales of diesel cars.

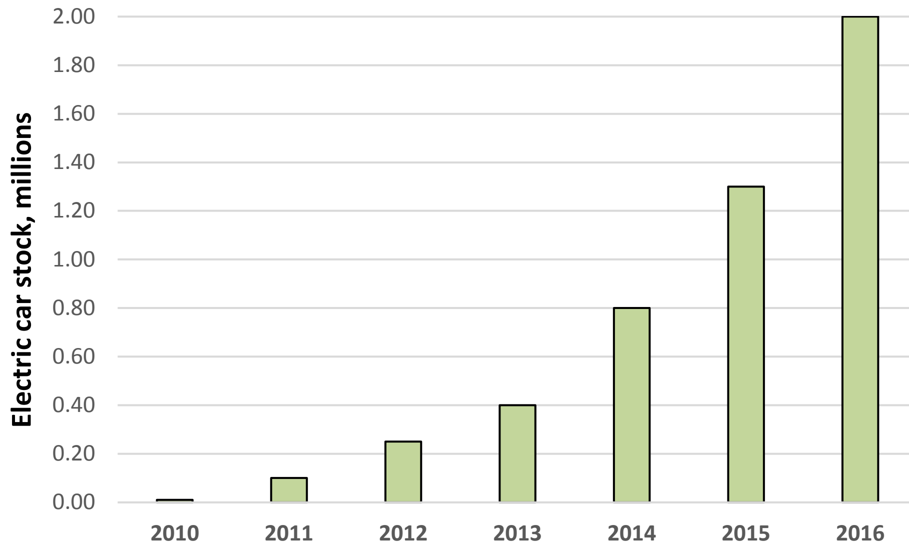

Fig. 6. Global sales of electric cars (Reuters, 2018).

Present renewable energy technologies offer a response to fossil options, albeit with limitations, primarily due to the still low energy conversion efficiency and the non-dispatch-ability of power generation. In the last decade, the market is dominated by photovoltaics (PV) and wind generators, which show a strong increase, while the capacities of big hydroelectric plants are rising at modest rates, as their potential has been utilised for decades now, especially in developed economies, Fig. 7. The overall contribution of the newly installed capacities in PVs and wind was 84% in 2018 (55% PVs and 29% wind), (Ren21, 2018).

The dominant problem with PV technologies is still the relatively high overall investment and their limited efficiency, although both have improved considerably in the last ten years. Nowadays, market available solar photovoltaic technologies are mainly silicon-based (about 95% of the market) with an energy conversion efficiency that usually ranges from 12% to 17% (Fraunhofer, 2019). The main current progress related to the development of new PV technologies is mainly expected in the area of organic and hybrid (organic-inorganic) Perovskite PVs, (Torabi et al., 2019), while other PV technologies are still in the early stage research, i.e. not close to the market implementation. Electricity production from the existing wind generation technologies can ensure an average efficiency from about 35% to 45%, with an average wind capacity factor of 20%–40% (windeurope, 2018), depending from the specific type of wind farm (offshore or onshore). The main present issues with wind generation technologies are their relatively high overall investment cost, which is a major issue for widespread implementation in less developed economies, where transmission grids also need to be developed, and, like in all renewables, the problem of intermittency (Boemi et al., 2013). To enable the efficient utilisation of renewable energy technologies, the key feature besides technological advances of the technologies as such is to ensure sufficient transnational energy connectivity, i.e. transmission grids, and to do this along with the development of novel and more efficient energy storage technologies. It is in this context that the EU has recently announced a new energy connectivity strategy with the main emphasis being on how to efficiently ensure energy connectivity between the EU and Asia, (Eeas.europa, 2019). The

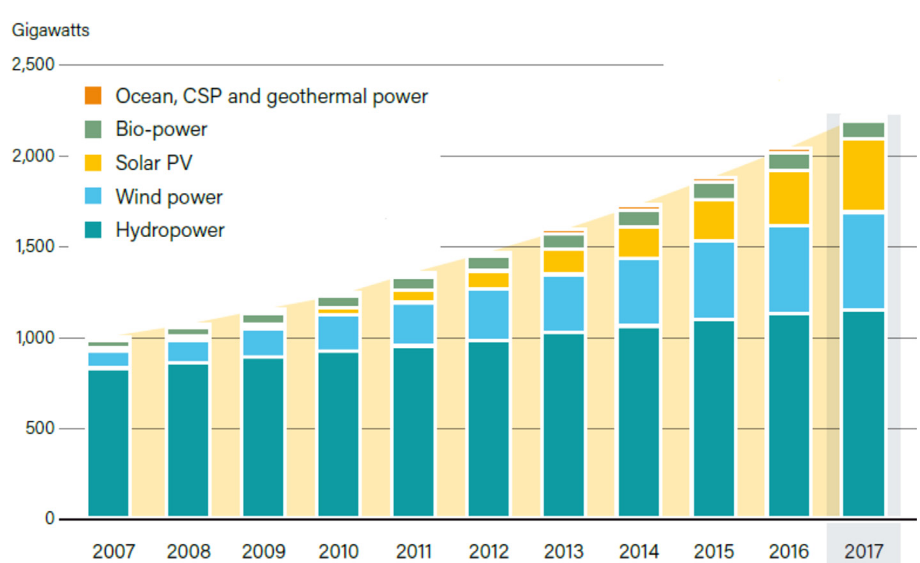

Fig. 7. Comparison of global renewable energy capacities (Ren21, 2018).

main EU energy connectivity target is to have an interconnection capacity of at least 15% between EU member countries, (Ec.europa, 2018). Global energy interconnection will remain one of the critical features to enable efficient penetration of renewables. Overall, solar PV and wind generation technologies are intensively progressing and will have a major role in the ongoing energy transition, (Irena, 2019). In this line of approach, the main goal of the energy transition is to ensure a safe and feasible pathway to shift from fossil-based economies to carbon-free economies, (Lee et al., 2018).

Further advances of existing energy storage technologies (flywheel, battery and thermal storage in general) are needed and especially in the case of lithium batteries, (Zhu et al., 2019). High demands are expected in global cumulative energy storage capacities, Fig. 8, considering the targeted shift to becoming a decarbonised society (i.e. to enable efficient intermittency of solar and wind technologies and to reduce transmission and distribution costs). According to the projections, approximately more than 900 GW of energy storage capacities will be needed by 2040, (About, 2018).

The main goals of novel or advanced existing energy storage technologies are to enable a reasonable duration (above 20 y, with significantly reduced degradation), acceptable unit cost and safety. It is interesting to note that, according to projections, only about 7% of assumed battery demands shuold be dedicated to stationary storage, while the unit prices of lithium and cobalt batteries will be affected due to the growing market of electric vehicles. On the other hand, the global rise in battery capacities will cause more intense environmental issues associated with battery technologies, (Tian et al., 2017), mainly in terms of usage of limited natural resources, photochemical pollution and acidification, the rise of CO_2 emissions, water pollution, ecotoxicity and recycling issues. The main challenges related to energy storage technologies will be directed to the overall improvement of their environmental suitability and cleaner production processes in general.

The rapid development of information technologies (IT) in recent years enabled a wide range of possibilities for a smart approach in various engineering applications such as the Smart City concept (O'Dwyer et al., 2019) and the implementation of Internet of Things (IoT) technologies (Srinidhi et al., 2019), which have recently become a hot topic in the research community. Based on a SCOPUS analysis, there is a significant rise in the number of research papers in the entioned topics, Fig. 9. In general, the sustainable aspect related to smart technologies is not sufficiently addressed by the research community concerning the individual research topics such as Smart City or IoT, Fig. 9.

The rapid urbanisation, with more than 50% of the global population already living in cities a figure that is expected to exceed 70% by 2050 (esa, 2014), intensifies all these problems, as the present infrastructure will not be able to bear the population pressure, especially when attempting to reach a sustainable

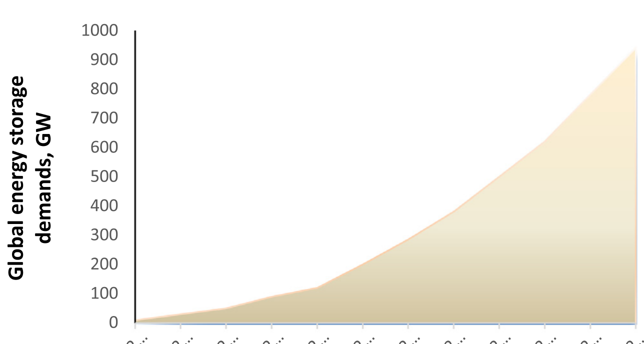

Fig. 8. Projection of global energy storage demands (About, 2018).

adaptation to novel circumstances. With the fast development of IT technologies, the Smart City concept could be a solution for cities, however coupled with the efficient application of IoT technologies. The fast development and implementation of smart technologies for various applications (Makate, 2019) is certainly opening new ways towards sustainability. In the long run it can cause environmental impacts that are still not sufficiently investigated. There is a steady, global rise in electronic waste, Fig. 10 (estimations are from 2017 to 2021) and the concerning fact is that only about 20% of globally produced electronic waste is being recycled (Collections, 2017). According to the latest projections the quantity of the electronic waste in 2050 would reach more than 120 million tonnes, (weforum, 2019). With the rapid development in the implementation of IoT technologies and smart concepts in general, and if no preventive actions are taken, this could cause serious sustainability issues and the demand arises for a smart and efficient electronic waste management (Ilankoon et al., 2018).

Benefits related to the implementation of smart technologies certainly exist and could be helpful to ensure further technological development, (Ismagilova et al., 2019). The cleaner aspect and general investigation of specific technological impacts on sustainability caused by the application of smart technologies need to be carefully checked to enable a balanced and sustainable progress of smart technologies.

1.3. Review methodology

Taking all these issues and challenges addressed into account, it becomes evident that major efforts in the research community should be focused, but not limited, on the following research topics;

- Further development of existing renewable energy technologies to become more economically viable, coupled with research of alternative and novel renewable-based energy technologies,
- Integration of renewable energy technologies in industrial applications as well as in buildings,
- Development of efficient energy storage technologies,
- More efficient utilisation of waste heat,
- Efficiency improvement of existing fossil-based energy conversion technologies,
- Development of cleaner transportation options especially in urban environments,
- Further progress in the efficient application of the circular economy concept and effective dealing with the plastic waste issues and efficient recycling technologies,
- Strategies to solve food-waste and electronic waste issues,
- Implementation of smart technologies as well as IoT technologies and investigation of their general impact on sustainability.

The main objective of this review editorial is to present and discuss the latest research findings and novelties in the field of smart technologies focused on efficiency improvement and effective utilisation of resources. It is serving as an introduction to the Virtual Special Issue (VSI) of JCLEPRO devoted to the 3rd International Conference on Smart and Sustainable Technologies (SplTtech2018) held on 26–29 June 2018 in Split, Croatia at the University of Split. A general methodology review will be elaborated and presented in the following sections.

The review conducted in this introduction editorial was focused on selected papers from the international conference SpliTech2018 and structurally divided into four main thematic areas (Green Buildings, Energy use and Consumption, Solar Energy Utilization, Efficiency and Waste Utilization and Smart Cities and Internet of Things). Besides the addressed selected and accepted VSI papers, each chapter has a brief introduction to the specific thematic areas,

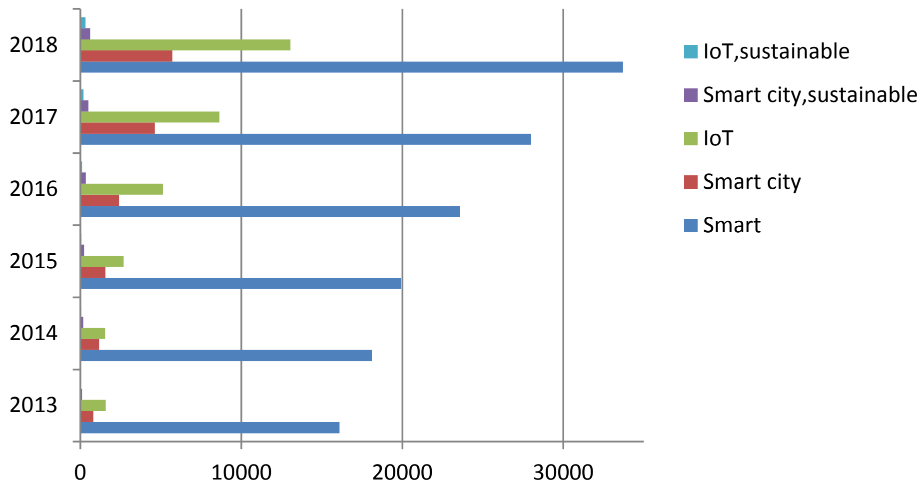

Fig. 9. Number of published papers in Scopus (Scopus, 2019), based on specific targeted keywords.

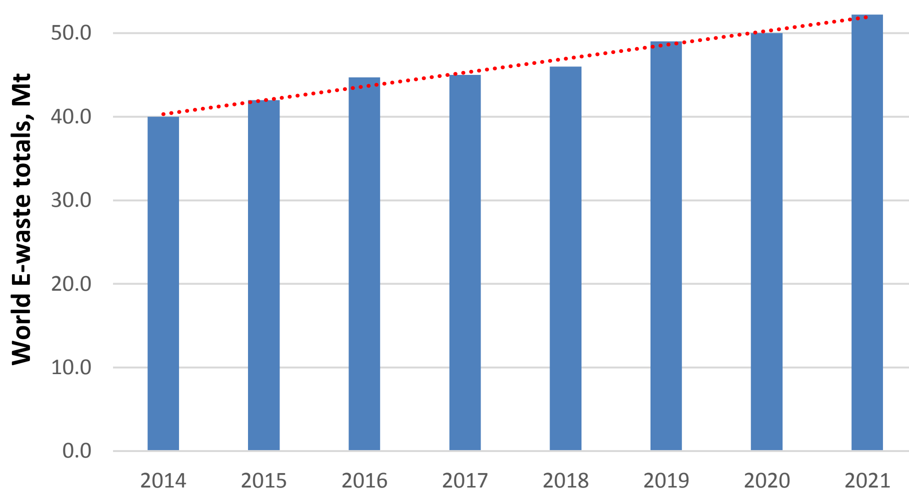

Fig. 10. Global rise of electronic waste, (Collections, 2017)

with the main current issues addressed in the field, together with relevant and latest references. Other contributions from the field have also been addressed as an addition to the selected SpliTech2018 papers published in JCLEPRO.

2. Green Buildings, Energy Use and Consumption

Buildings are responsible for about 40% (eia.gov, 2018) of the overall end-use energy consumption and have a higher share when compared to other global end-use energy sectors (industry and transportation), Fig. 11. The residential building sector usually consumes more energy than the commercial sector. Most of the energy demands in the residential sector are related to space heating and hot water preparation, while it is primarily HVAC systems and lighting in the commercial sector.

Buildings are identified as severe pollutants with a share of CO_2 emissions ranging from 30% to 40%, (Xilong et al., ' 2015), depending on the specific economy. Besides CO_2 emissions, buildings are also responsible for other impacts on the environment, mostly air and water-based pollution caused by cement plants, (Raffetti et al., ' 2019). According to the projections of heating, cooling and hot water preparation demands, a rising trend is expected and mainly in the residential sector, (Ürge-Vorsatz et al., 2015), Fig. 12. The residential sector will be especially affected with a significant rise in cooling demands due to global warming issues in upcoming years, (Jakubcionis and Carlsson, 2017).

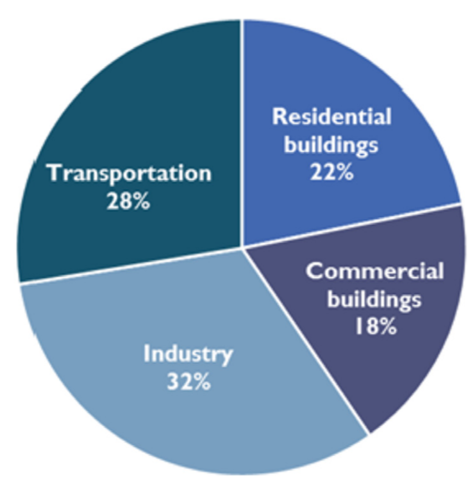

Fig. 11. Total energy consumption by end use for buildings with respect to other energy consumption sectors, (Bcapcodes, 2017)

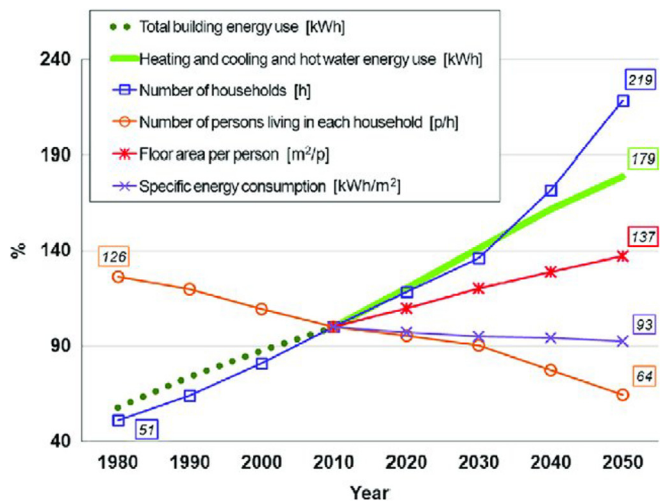

Fig. 12. Heating and cooling trends in buildings (Ürge-Vorsatz et al., 2015),

The introduction of the Nearly Zero Energy Buildings (NZEB) concept (Harkouss et al., 2018) could be a proper response to restraining energy consumption in buildings concerning the previously addressed future projections. According to the Energy Performance of Buildings Directive (EPBD), all new buildings in the EU will need to be NZEB by the end of 2020, (Ec.europa, 2019). The previous goal is challenging and will require significant research efforts to bring novel technological solutions that will help countries to adapt to the new building standards and implementation strategies in reasonable time, (Asaee et al., 2019). One of the major issues related to NZEB or passive buildings is related to air-quality (Poppendieck et al., 2015) concerning the general airtightness of high-performance buildings, (Feijó-Muñoz et al., 2019). Effective ventilation strategies strongly depend on the specific climate circumstances as well as general building characteristics. More research efforts are needed to analyse effective ventilation strategies for high-performance buildings in different climates, (Grigoropoulos et al., 2017). The building envelope performance is a critical feature to reach the expected NZEB standard and to reduce overall heating/cooling demands. Novel strategies are needed to discover cost-optimal solutions in different climates, i.e. to enable the optimal design of NZEB buildings for various types of buildings, (Sankelo et al., 2019). From the previous aspect, the development and consideration of novel building envelope materials should be further provided to discover effective and economically viable solutions, (Huang et al., 2019a). An important aspect in the general NZEB building design is to ensure the efficient implementation of renewable energy technologies through different hybrid energy solutions, (Nižetić and Čoko, 2014). The residential sector in cities and densely populated areas (condominium building facilities) is demanding and challenging to reach the high penetration of renewables due to physical limitations, so efficient technologies followed by proper supportive policies are necessary to reach NZEB target, (McElroy and Rosenow, 2019).

The use of highly efficient renewable energy systems, smartly integrated into urban buildings, can significantly contribute towards net positive energy buildings, which should be the mainstay of 21st-century prosumers, blurring the line between 20th century energy consumers and producers (Baljit et al., 2016). This new role, however, should be coupled with new, ambivalent, smart electricity distribution grids and smart metering systems, (Shukla et al., 2019). In general, the encouragement of Energy efficiency measures in buildings is a valuable opportunity for economies, both to generally reduce energy demands and help to generate green-related jobs, (Alreshidi, 2018). Present energy efficiency measures in buildings are primarily focused on constructional building elements (building envelope, openings, thermal bridges issue) as a logical path to reduce general building energy demands, but not limited to other important technological solutions in buildings that needs to be explored. The following sections of this review editorial are related to the latest advancements within this specific thematic topical area.

Automatization in district heating systems (Guelpa et al., 2019) is very important since it enables sensible improvement in energy efficiency and in general efficient automatization is nowadays one of the main goals in different energy-related sectors. In the conducted study (Lazarevic et al., 2019), a novel mathematical model was proposed and followed by a developed numerical simulation model using LabVIEW. The developed simulation model enabled accurate and precise monitoring of the heat substation operation. The main advantage of the developed model is in its possibility to be applied on actual heating systems with the possibility to enable efficient control strategies, i.e. to enable further optimization of the overall system performance (model can be used for fault detection and diagnosis of heat substations based on real data). The development of Efficient building energy modelling (BEM) tools is valuable (Farzaneh et al., 2019), since there is a gap between measured and predicted energy demands in buildings, Fig. 13. Mentioned gap depends on the age of the specific building facility, i.e. from the building standards, (Yan et al., 2015). Occupant impact, i.e. behaviour is the most demanding feature that significantly contributes to the mentioned gap between the designed (predicted) and measures building energy performance. Occupant monitoring and then the development of novel models, incorporated in the building simulation tools, are still challenging research tasks with considerable space for improvement, (Mun et al., 2019).

As already addressed, an essential aspect in buildings is indoor air quality as well as the reach of proper thermal comfort conditions, which become emphasised especially in the case of nearly zero energy buildings NZEB (Liu et al., 2019). A review related to the indoor air quality, with respect to human health and productivity, was obtained in (Mujan et al., 2019) with reported latest research findings addressed in the existing literature. The previously mentioned study addressed different influential factors that can be

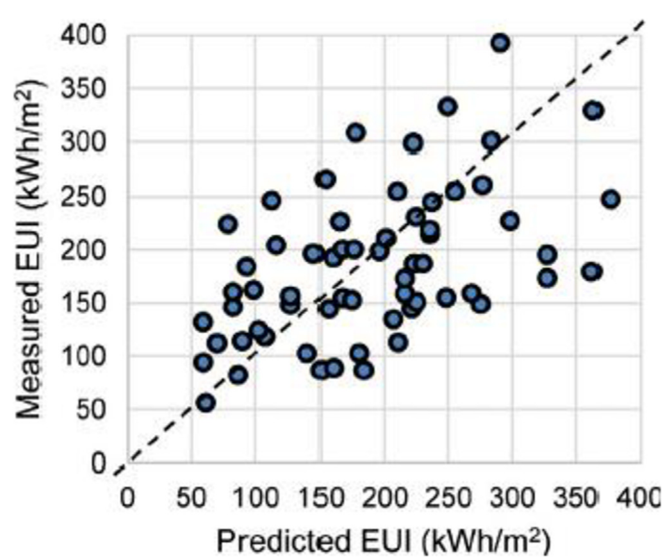

Fig. 13. Gap between measured and predicted building energy demands, (Yan et al., 2015).

measured and controlled, and that affect indoor air quality, i.e. finally human productivity. Different challenges were discussed, as well as further necessary research efforts to ensure minimum requirements and a healthy environment in buildings. General ventilation approaches regarding NZEB buildings were discussed in (Medved et al., 2019) where major driver for the future development of ventilation systems would be through assumed building thermal mass utilization in different periods of the year. With the involvement of novel constructional materials in buildings and different coatings, different indoor emission sources are being enabled, and that can have harmful effects on human health in closed building environments. Risk exposure to different indoor aerosols was reported in (Koivisto et al., 2019), where all influential parameters related to specific indoor emissions were detected and discussed systematically.

The preparation of domestic hot water (DHW) requires noticeable energy demands together with space heating, Fig. 14. With respect to the general energy efficiency targets in building stocks, an important feature is to investigate the opportunities that can lead to the energy efficiency improvement of DHW systems (Dahash et al., 2019). Besides space heating demands, water heating demands play a significant role in the case of residential building facilities. More efficient utilization, as well as the development of novel hot water preparation systems (Lyu et al., 2019), should be delivered in the future research efforts.

Experimental, i.e. field investigation on multifamily buildings was reported in (Tomasz et al., 2019) and focused on effective and low-cost methods to reduce heat consumption in present domestic hot water systems. Based on the conducted field study (long term measurements), and depending from the type of specific building facilities, the detected share of heat losses in the overall heat consumption ranged from about 56% to 70%, and associated with the DHW preparation systems, Fig. 15.

With the proposal of specific measures in DHW preparation systems, the calculated energy savings ranged from 6% to almost 50%, depending on the specific group of objects and assumed energy efficiency measures. According to the results of the previously addressed latest research study, potential for energy savings in DHW systems is obvious and actions should be directed in a systematic and policy-based manner for the encouragement of energy efficiency measures in DHW systems.

An efficient building envelope is a critical feature towards NZEB and high-performance buildings, however, besides the convectional building envelope, novel and innovative solutions are needed to be able to reach the NZEB standard as already addressed. The integration of vegetation in architectural buildings, as green walls, represents an approach that can bring specific benefits to the effective temperature balance of the walls. An experimental study

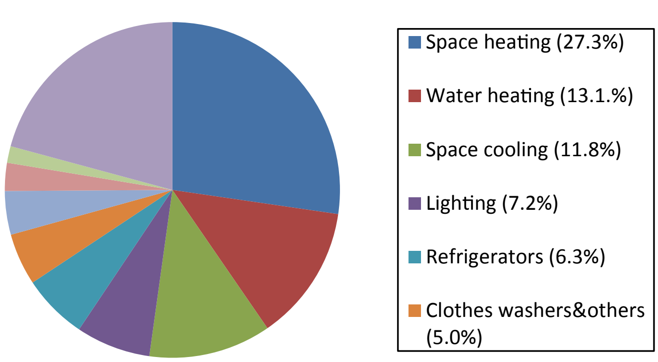

Fig. 14. Average structure of residential building energy use for USA in 2015, (needtoknow, 2019).

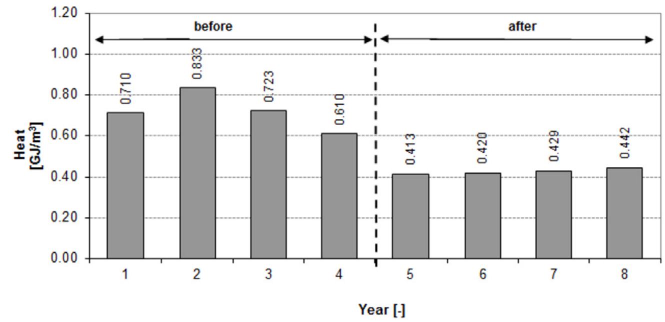

Fig. 15. Comparison of DHW heating demands before and after application of energy efficiency measures (Tomasz et al., 2019).

with assumed green walls was conducted for Belgrade climate conditions, together with theoretical analysis, (Sudimac et al., 2019). The application of vegetation (Fig. 16) was associated with the reduction of external surface wall temperatures ranging from 0.5 °C to 14 °C, depending on the specific period of the year.

According to the authors, the main potential of green walls is the enabled passive cooling of the building walls and future investigations should be intensified in that direction. A novel nanocomposite phase-change material for potential application in buildings was elaborated in (Putra et al., 2019). Beeswax/multiwalled carbon nanotubes were considered, and experimental results proved that the thermal conductivity of the novel material was increased to factor 2 with proved high heat storage capability. Massive application of wooden materials in the case of multi-storey building facilities was analysed by (Bruno et al., 2019). The design requirements were discussed in the previous study to reach the NZEB standard in Mediterranean climate conditions. The structural safety of wooden elements was also analysed with a precise provided layout of cross laminated timber panels. The concept of novel super insulating panels/systems, based on silica aerogels, was elaborated in (Ibrahim et al., 2019) with potential for building application. The proposed novel building thermal insulation system was experimentally tested and based on the measured data the U-value was significantly reduced (from 0.66 W/m^{2}K to 0.33 W/m^{2}K) and the novel material showed reasonable resistance to wall moisture risks.

Fig. 16. A segment of green wall examined in (Sudimac et al., 2019).

The effect of thermal bridges is noticeable in the case of new buildings due to strict imposed regulations related to the general performance of the building envelope and due to specific building design, (Danza et al., 2018). An analysis of different thermal bridge scenarios was obtained in (Theodosiou et al., 2019), where the detected portion of heat flows due to thermal bridges, was more than 25% in the case of the analysed advanced cladding systems. The cause for the relatively high impact of thermal bridges is due to the overlook of basic energy efficiency parameters. The study revealed that the oversimplification of regulations and finally underestimation of thermal insulation protection is most influential. The impact of brackets in double skin façades were found to be crucial due to intense heat flows, Fig. 17, so thermal brakes within the bracket body are suggested.

To enable an efficient improvement of advanced façade systems, an integrated approach is required, with imposed innovated technical characteristics that are beyond existing building codes, (Papadopoulos, 2016). Aerogel-enhanced blankets were analysed in (Berardi and Ákos, 2019) as a potential technology to reduce thermal bridging effects in building applications. Laboratory investigations revealed that the considered silica Aerogel-enhanced blanket could be an effective solution for the reduction of heat losses caused by thermal bridges. The economic aspect was not addressed in the previous study which is a critical feature, and that needs to be further discussed. Novel mathematical tools were elaborated in (Sfarra et al., 2019) for the efficient detection of thermal bridges in buildings. The novel developed multiscale data analysis method (Iterative Filtering- IF) allows efficient detection and optimisation of thermal bridges. A few case studies were discussed where the developed mathematical tool was applied for the detection and analysis of thermal bridges. The thermal behaviours of the five patented slab front (slab-façade) concepts were discussed in (Bienvenido-Huertas et al., 2018). The gained results showed that linear thermal transmittance could be significantly reduced for the analysed cases. It was also detected that with the examined patented solutions, it was possible to reduce heating demands by more than 18% and cooling demands by almost 3.0%.

The thread that runs through the conclusions of recent papers linked with the herein considered thematic area is that there is a bi-directional relationship between the political, regulatory and socioeconomic developments and general progress is evident in the field of building systems and materials, (Pezeshki et al., 2019). The ever-stricter regulation acts as the driving forces for the development of effective insulating materials (Tettey et al., 2019), airtight buildings (Tanyer et al., 2018) and smart façades (Juaristi et al., 2018). It is also important address the importance of Micro-CHP, high performance HVAC systems, smart-grids and predictive BACS systems (Building Automation and Control Systems). It is the availability of these building elements and materials that enable the implementation of ambitious and innovative designs towards efficient and high-performance buildings (Nižetić et al., 2017a). The main progress in this field should be directed towards a more efficient and economically viable integration of existing renewable energy technologies in buildings and more efficient demands side management. Buildings should become energy producers and the opportunity to reach a balanced energy infrastructure in cities that are continuously developing, becoming more demanding from an infrastructure point of view. Progress could only be made with the close collaboration of all engineering disciplines that are involved in the general building sector.

3. Solar energy utilisation

Solar energy utilisation is nowadays focused on electricity production from photovoltaic (PV) technologies (Schmidt et al., 2018) or heat production from various solar-thermal systems (Sakhaei and Valipour, 2019). There are also integrated photovoltaic-thermal PV/T systems (Jia et al., 2019), that are capable of producing both thermal energy output as well as electricity, however, currently less market attractive due to a relatively high overall investment cost. The global growth of installed PV capacities reached more than 100 GW in 2018, where the dominant market leader has been China with 47% of overall installed PV capacities in 2018 and the largest producer of PVs, Fig. 18, (Genentech Media, 2018).

The main technical barriers of market available PV technologies were already addressed in the introduction section. There are significant research efforts to enable more efficient and novel PV technologies such as perovskite (Torabi et al., 2019), organic (Senthil and Yuvaraj, 2019), or ones with the assumed application of nano-technologies (Brekke et al., 2018), such as nanopillar solar

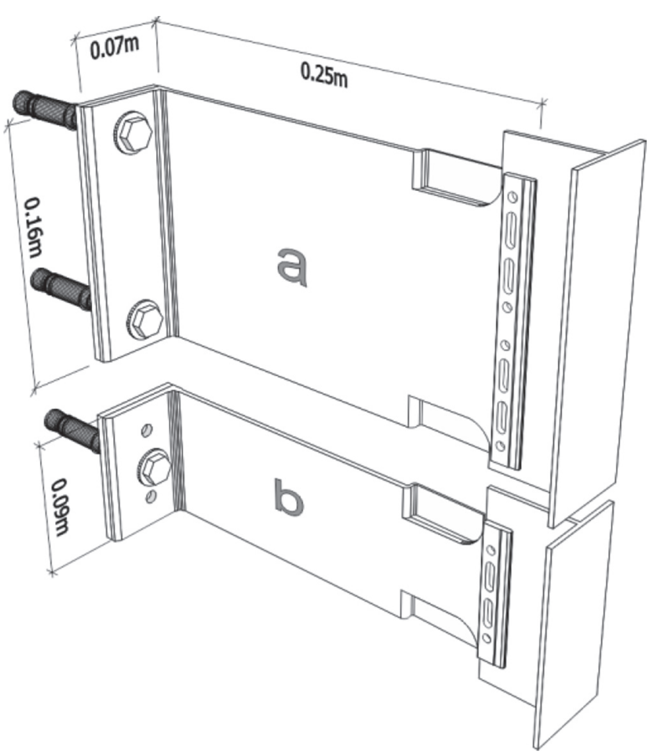

Fig. 17. Examined bracket geometry (Theodosiou et al., 2019),

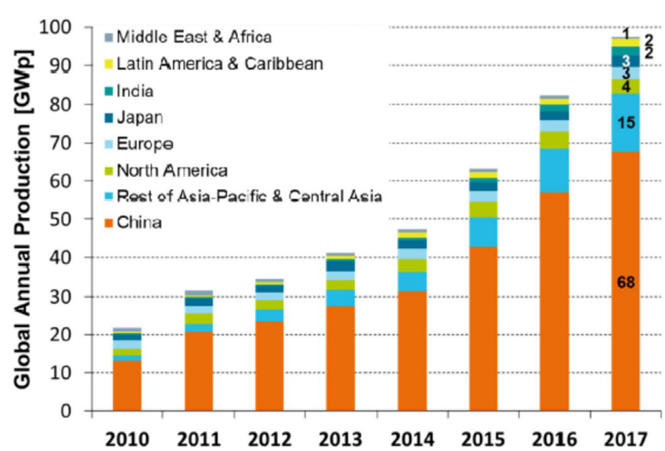

Fig. 18. Global annual production of PVs (Fraunhofer, 2019).

cells (Youngjo et al., 2017). The previously mentioned novel PV technologies are still not ready for an expected wide market application, due to present technical shortcomings and unfavourable economic viability. Among the most promising ones are Perovskite PV technologies (in metal halide variant). According to the latest research findings, they could reach a relatively high energy conversion efficiency (over 20%), with LCOE (Levelized Cost of Electricity) ranging from 4.93 to 7.90 USD cents/kW, (Song et al., 2017). However, they are still open technical issues regarding the stability of Perovskite PV cells long term (i.e. their lifetime), the applicability of technology for large scale PV systems and environmental impacts due to the use of organic solvents. Discussion on all current technological issues related to Perovskite PV technologies can be found in (Djurišić et al., 2017). If those technical deficiencies are solved in the near future, Perovskite PV cells become the cheapest PV power generation technology on the market.

Other present research efforts are more focused on the development of existing market available PV technologies (silicon-based PVs) or associated systems and components (further simplification of production processes, reduction of material waste, efficiency increase, etc.). There are also other technical issues related to widely available silicon-based PV technologies, such as efficiency degradation due to elevated operating temperatures (Grubišić-Čabo et al., 2016) or accumulated dust and its general impact on electricity production (Cen et al., 2018). Moreover, in some countries, there are also legislative issues, which discourage a wider implementation of PVs, (Talavera et al., 2016). Besides all the previously mentioned issues, silicon-based PV technologies have stable growth on an annual basis and are becoming a dominant renewable energy electricity source.

The development of hybrid energy systems could be an effective solution for the integration of various market available renewable energy technologies based on the utilisation of solar energy. Recent research findings are focused on the investigation of different hybrid energy options for residential applications (Bartolucci et al., 2019a), or other applications. An energy management strategy for the improvement of the control strategy in the case of hybrid renewable energy systems for residential applications was elaborated in (Bartolucci et al., 2019b). The novel control strategy allowed correlation between real-time field data and historical consumption data, which enabled a reduction in the energy to unbalance as well as operational costs. The increased implementation of electric vehicles in urban environments requires the investigation of different scenarios where hybrid energy systems could play an important role. A framework for the optimal planning of renewables with actual electric loads was analysed in (Bagheri et al., 2019) to reach low-carbon communities. The main results of the obtained study are reflected through the development of effective policies for the integration of hybrid and renewable based energy systems in urban environments. The electrification of Sub-Saharan Africa with the application of PV/hybrid mini-grids was elaborated in (Moner-Girona et al., 2018). Based on the conducted review, it was found that mini-grids represent an effective option for the development of viable business models. The main issue is detected a quality gap between existing business models and ones related to the effective implementation of PV/hybrid projects. The investigation of energy mix (photovoltaic-wind-diesel hybrid system) was addressed in (Ferrari et al., 2018) for the case of remote off-grid applications in Italy. The gained results revealed that it is possible to achieve economic and environmental benefits with the proper optimisation of the hybrid energy system for remote consumers.

The integration of electric vehicles (EV) was addressed in (Coffman et al., 2017) with respect to residential PV systems. The study revealed that EV subsidies need to be considered on a regional level and that the implementation of EVs is a rather costly option for the reduction of CO_2 emissions in Hawaii case. A policy review related to solar PV systems as well as an economic analysis of On-grid PV systems was addressed in (Hassan et al., 2019a) for residential facilities in the Philippines. The obtained analysis showed that the most attractive one was a 100 kW PV system with a cost-benefit ratio of 4.17 and a simple payback period of about 4.0 y. The current policy related to PV systems in the Philippines could be improved with the introduction of the additional supporting mechanisms were discussed in the same study.

The efficiency improvement of market available PV systems and their components leads to higher installed PV capacities on a global scale. The efficiency increase of PV systems could be reached with proper maximum power point (MMPT) strategies and different control approaches that have been intensively investigated in recent years, (Mohapatra et al., 2017). A new algorithm related to a novel bio-inspired optimisation method, named memetic salp swarm algorithm (MSSA) was proposed in (Yang et al., 2019a). The developed MSSA is primarily applicable for the efficient tracking of maximum power point for photovoltaics. Four different cases were studied for Hong Kong climate conditions. The gained response from the MPPT system was compared with eight different MPPT algorithms (incremental conductance, genetic algorithm, particle swarm optimisation, etc.). The gained results showed that the proposed MSSA algorithm is more effective when compared to other MMPT strategies (the system can produce more electricity with less emphasised power fluctuations). Future research work will be focused on the application of the proposed algorithm on real PV panels, i.e., to check its suitability in realistic circumstances. A novel maximum power tracking (MPPT) algorithm for PVs was proposed and elaborated in (Grgic et al., 2019). The main difference in the proposed approach, when compared to conventional ones, is that it does not require a PV array current measurement, and excludes oscillation around the MPPT (which is often used in standard MPPT approaches). A simulation model was developed to determine the impact of the different operating conditions on the overall system performance. The model was applied to various possible operating conditions, and the results showed to be approximately 7% more efficient when compared to other MMPT control approaches (with respect to nominal power). A wind-driven optimization algorithm for PVs operating under non-uniform solar conditions was discussed in (Abdalla et al., 2019). The Wind-Driven Optimization algorithm was applied, and results showed that the applied approach ensured a more effective optimisation tool when compared to the other convectional MPPT optimisation strategies (such as particle swarm optimisation, differential evolution, harmony search algorithm, etc.). A novel three-layer voltage/var control strategy (VVC) for the coordination of VVC devices in the case of PV clusters was addressed in (Li et al., 2019a,b). The proposed control strategy enables the monitoring of voltage deviations as well as system voltage stability. A central approach was applied on two layers, and the model showed to be an effective tool for the control of the PV cluster. Voltage was provided in the safe range which can improve the complete voltage stability of PV cluster in general.

A critical practical feature associated with the application of PV systems is the effect of the accumulated dust and its impact on PV panel performance (Gürtürk et al., 2018). Different cleaning approaches were widely analysed and discussed in recent research studies as efficient approaches to replace expensive labour based cleaning that also consumes relatively large water quantities. A novel concept of cleaning robots for PV panels was presented in (Shibo et al., 2019). The proposed autonomous robot solution, Fig. 19, can clean PV panels in an effective manner and an experimental approach was conducted to detect real performance, while

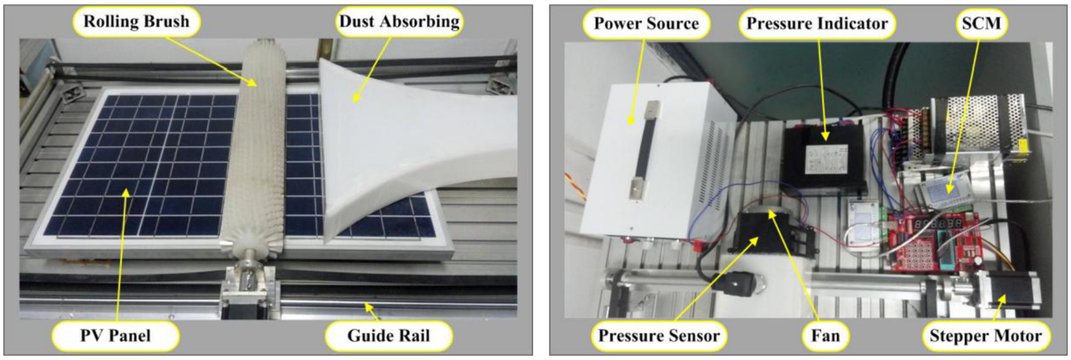

Fig. 19. Experimental setup of cleaning robot with signal collecting module (Shibo et al., 2019))

CFD model was also developed to optimise structural parameters. Influential parameters regarding system performance were analysed and discussed with defined optimal values related to the inlet width and height, outlet width and height and necking radius.

An experimental approach focused to the cleaning of large solar PV plants in dessert climates was reported in (Al-Housani et al., 2019). Autonomous drone cleaning was considered with microfiber based-cloth wipers, and the results showed efficiency improvement due to the provided cleaning from 3.1% to 7.7%, depending on the specific period of the year. Automated, robotic dry-cleaning of PV panels was discussed in (Parrott et al., 2018) for Saudi Arabian climate conditions. A silicon rubber brush was applied as a cleaning strategy, and the study generally revealed that robotic cleaning reduced unfavourable dust effects and increased PV panel power output. The main advantage of the proposed cleaning approach is its low cost and excluded damage of PV panel front surface. A novel portable robot solution design for the cleaning of photovoltaic systems was presented in (Al Baloushi et al., 2018), targeted for applications in desert areas. Based on the field results, the cleaning system was able to ensure an increase in PV system efficiency with a reduced quantity of wasted water (and less labour cost). Water free and automated cleaning solution for PVs was proposed in (Deb and Brahmbhatt, 2018). The technical specifications of the automated cleaning system were reported together with a conducted review related to soiling prevention methods.

Photovoltaic-thermal (PV/T) systems, Fig. 20 are attractive from a technical point of view since they can produce both electricity and thermal output from available solar irradiation. The PV/T systems are combined with a sort of thermal energy storage to improve overall system efficiency. PV/T systems are especially interesting for potential integration in hybrid energy systems regarding different applications. As already addressed, a critical feature of the PV/T systems is their high initial unit cos and further development of photovoltaic-thermal (PV/T) systems is necessary to improve overall system efficiency and reduce unit costs, (Jia et al., 2019). From the previous point of view, different PV/T configurations have been recently investigated and mainly focused on the techno-economic aspect.

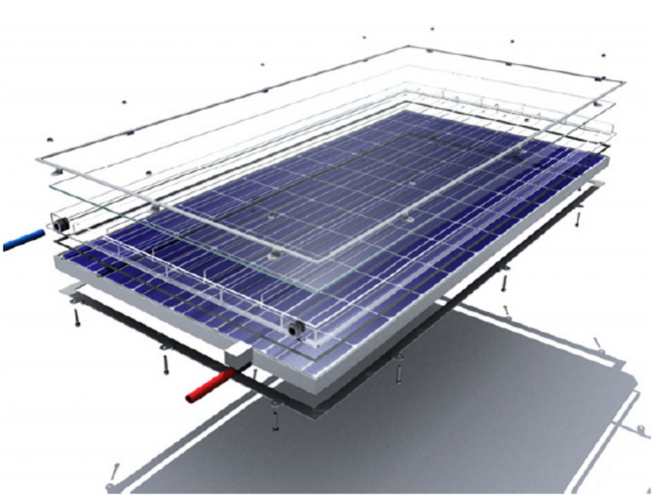

Fig. 20. Example of specific PV/T design (Rosa Clot et al., 2011),

A comparison of PV/T systems was analyzed and discussed in (Gagliano et al., 2019) in the case when PV/T systems were compared with the PV plant with an incorporated solar thermal storage (PV + ST). The study was conducted for different geographical locations in the EU region (Catania, Split and Freiburg). The energy analysis was focused on residential buildings and conducted using the TRNSYS simulation tool. Different scenarios are being simulated, together with addressed economic aspect. The results revealed that overall the PV/T plant could produce more total energy when compared to a single PV system for all the considered locations. A PV/T plant can gain higher total energy production when compared to the best PV + ST configuration. It was also possible to achieve a reduction in primary energy consumption with the application of the PV/T plant. The economic analysis showed that the PV/T configuration is economically viable, but only for the locations of Catania and Freiburg, while for the location of Split, the cheap energy cost affects the overall economy. However, the conclusion is that the PV/T configuration is a generally more effective solution when compared to the examined PV + ST configuration for the analysed geographical locations. An experimental study of a hybrid PV/T system (attached water cooling system on the backside surface of PV panel) was discussed in (Salem Ahmed et al., 2019) for Egyptian climate conditions. The average efficiency of the PV panel was higher for about 8% when compared to the non-cooled PV panel, while the maximal overall system efficiency ranged from 68% to 74%. A micro PV/T system was proposed for operation in moderate climates with a provided experimental study in the location of Pataras, Greece (Bigorajski and Chwieduk, 2019). A simulation model was developed, and the energy performance of the system was checked. The system was only tested in December and January, so one of the main open issues is the potential overheating issue in summer months (and which was not tested). A modular PV/T façade technology was compared with flat integrated collector storage (ICS) in (Smyth et al., 2019). Hybrid PV/T façade technology can be used for space heating, hot water preparation and electricity generation. The proposed hybrid technology is suitable for building retrofit applications. The experimental results revealed that the thermal efficiency was higher in the case of the ICS technology in the amount of 5%–10% when compared with the hybrid technology. When the produced electricity from the hybrid PV/T system was included, then the overall system efficiencies were equal. An energy, exergy and economic analysis of two sides serpentine flow based PV/T systems with the application of phase change materials (PCM) were elaborated in (Hossain et al., 2019a). According to the experimental results, the maximal thermal efficiency of the examined system almost reached 88%, while the maximal electric efficiency was around 12% (efficiency of single PV panel was about 7%). An economic analysis was also conducted to examine the feasibility of the proposed PV/T-PCM system. A hybrid PV/T system with Nano fluid as working fluid (water-based Multi Walls Carbon Nano Tubes) was elaborated in a reported study (Abdallah et al., 2019). The addition of nano-particles caused the improvement of thermal properties and electrical efficiency of the hybrid PV/T system. The highest overall system efficiency reached about 83% with a nano-particle volume concentration of 0.0075%. The average efficiency of the system was over 61% with an average reduction in the operating temperature of the system of about 10 °C.

As previously mentioned, one of the critical issues related to the practical application of PVs is the present efficiency degradation due to elevated operating temperatures. Different cooling strategies for PVs have been investigated in recent years that can either be passive (Nižetić et al., 2017b) or active one (Nižetić et al., 2018a,b). The main target of the examined cooling methods was related to the efficiency improvement of existing PV systems in different applications (building integrated PVs-BIPB, concentration PVs – CPV, etc.). A novel thermal management system for concentrated PV systems (CPV) was presented and elaborated in (Manikandana et al., 2019). The proposed cooling concept for the CPV system assumes the application of phase change materials (PCM), applied on the backside surface of the PV panel, Fig. 21. A numerical simulation model was developed using COMSOL Multiphysics software. The gained results showed that it is possible to reduce the operating temperature of the PV panel by more than 20 °C, with an increase of over 20% in PV panel output (when compared to non-cooled PV panel). The thickness of the PCM layer was found to be a critical feature for system performance. An economic aspect of the proposed concept was not discussed in the study, and an experimental approach is needed to determine the economic viability of the proposed cooling configuration.

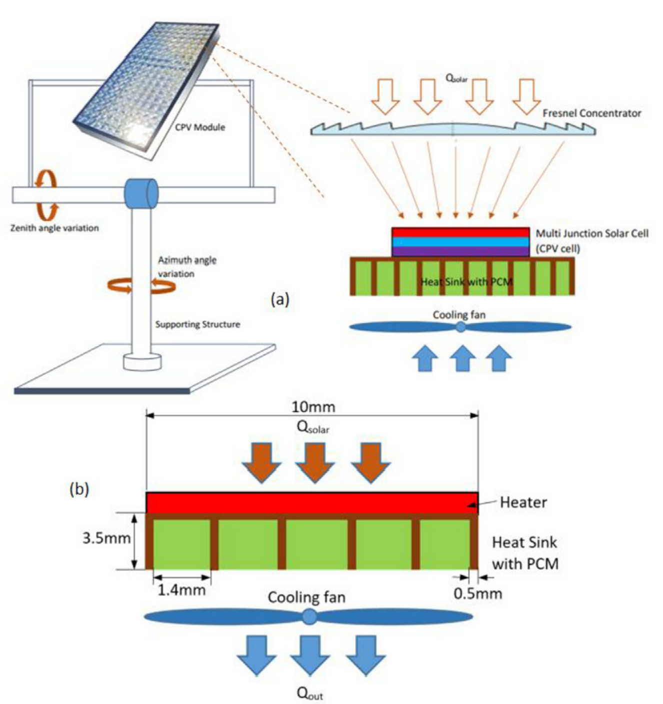

Fig. 21. Sketch of novel thermal management concept for CPV systems (Manikandana et al., 2019).

In the case of concentrating CPV energy conversion technologies, the main technical barrier is the fact that incoming energy being dissipated as heat in an amount about 60% and different cooling strategies were investigated to make CPV systems more economically viable. A passively cooled hybrid thermoelectric generator-concentrator for CPV systems was addressed in (Rodrigo et al., 2019). The modelling for a CPV system with thermoelectric cooling was obtained from a performance and economic point of view. Optimal solutions were analysed to ensure the cost reduction of the considered CPV system through efficiency improvement. A sensitivity analysis of the main influential parameters was done to detect the trade-off between efficiency and cost reduction. The gained results are very useful as a guideline for the development of novel and more efficient CPV prototypes.

A transmissive microfluidic active cooling system for CPV application was proposed and discussed in (Islam et al., 2019). Configuration consisted of several parallel micro-channels attached on the CPV module. Total transmittance of the CPV was reduced for about 5%, which caused a reduction of the peak cell temperature. Economic aspect was not addressed and which should be a step further. General performance analysis of passive radiative cooling methods for PVs was elaborated in (Li et al., 2019a,b). It was found that with an elective spectral, passive radiative and combined cooling, an increase in energy conversion efficiency could be achieved from 0.98% to 4.55%. The passive cooling potential was analysed for different regions in China where it was found that the efficiency improvement ranged from 2% to 2.5%, depending from the specific geographical location. LCOE analysis was also obtained to explore the economic viability of the proposed concepts. The proposed design allowed total transmittance reduction for the CPV modules by 5.2%. The addition of active cooling micro-channels turned out to be an effective design solution. The application of a microchannel heat sink with nanofluid as coolant was reported in (Radwan and Ahmed, 2018) for CPV applications. A three-dimensional model was developed and validated with experimental data for Egyptian climate conditions. It was found that the increase of the nanoparticle volume fraction ratio significantly reduces the cell operating temperature and improves cell efficiency. The reduction in maximal solar cell temperature ranged from 3 °C to 8 °C when compared with water. However, the economic aspect of the proposed solution was not discussed as it was the case in other studies. An investigation of pork-fat as a novel PCM material for PV-PCM cooling was elaborated in (Nižetić et al., 2018a,b). The study revealed that pork fat could be a viable PCM material regarding thermal properties and a simulation study was conducted for two cities in Turkey through the developed numerical model. The main issue is the long-term stability of the pork fat physical properties. Since pork fat has significantly lower unit costs when compared to other conventionally applied PCM materials, investigations towards that direction are worthwhile. The application of aluminium fins as a passive cooling strategy for silicon-based PV panels was reported in (Grubišić-Čabo et al., 2018). The experimental study was conducted on two 50 W Si-poly PV panels and the gained results showed the techno-economic potential of the cooling technique. Proposed cooling technique needs to be further experimentally tested on larger PV panels to get credible conclusions. Interesting work related to unconventional passive cooling approaches for PVs based on sub-bandgap absorption and imperfect thermal radiation was addressed in (Sun et al., 2017). The main idea of the study deals with the elimination of parasitic absorption with the redesign of the PV panel optical properties and improvement of thermal emission with radiative cooling. Based on the proposed actions and conducted simulations, it was concluded that the reduction in PV panel operating temperature could reach up to 10 °C. Passive self-cooling has potential but needs to be further explored by conducted experimental approach.

This section briefly addresses and overview of the latest research findings related to solar energy utilization. From a research perspective, the focus of research activity is the further consideration of potential applications of current market available PV technologies through CPV, BIPV and PV/T systems. Some innovative solutions have been discussed where there are still technical deficiencies that need to be solved in order to ensure economically viable solutions suitable for the market application. The integration of present PV technologies is critical in hybrid energy systems, especially for residential application in buildings; more techno-economic studies are therefore needed to discover effective and viable solutions for the targeted applications. Significant research efforts are also directed towards the efficiency improvement of convectional PV systems, mainly to address advances in control and regulation approaches via innovative technical solutions related to the efficient cleaning of PV panels in demanding environments. Cooling techniques for PV panels have also been extensively investigated for efficiency improvement, where the most attractive ones are passive cooling strategies. Lately, radiative cooling approaches for PVs have been intensively investigated, and a potential exists for efficiency improvement with the introduced redesign of optical properties. Therefore, more research should be provided in the near future related to the development of radiative cooling techniques for PVs. Economic and environmental aspects related to cooling technologies for PV panels are not sufficiently addressed, i.e. the research studies were mostly focused on performance improvement. Novel PV technologies are still in their mature stage and still not widely applicable to the market. The most promising ones are Perovskite PV technologies, which are currently in the focus of the research community. The herein addressed recent research studies demonstrated that further developments in the field are needed to ensure more efficient solar energy utilization.

4. Efficiency and Waste Elimination

In an engineering approach, one should eventually comply with the two laws of thermodynamics: Maximizing the efficiency and minimising entropy on the one hand and reducing the use of resources, as the world is a closed system, where mass flows present the ultimate strain for urban biospheres. Efficiency improvement of existing market available technologies, systems, processes or specific components has become a necessity to be able to reach general sustainability goals for different cases, i.e. engineering applications.

Research studies based on the Scopus research database (Scopus, 2019), revealed a considerable rise in research papers focused on efficiency, 149,533 published papers in 2016 specifically to 175,072 published papers in 2018. A significant interest of the research community is related to energy efficiency topic with 38,402 published papers in 2016 and 47,064 published papers in 2018. The research topics are mainly related to energy efficiency in buildings, transport, industry or efficiency analyses for different technologies, processes and products. Efficiency improvement for various engineering applications and efficient waste elimination management are crucial population problems, so an overview of recent advancements will be provided in the continuation of this review paper. Since the herein addressed topic area of efficiency is wide, the herein presented overview is limited to specific engineering issues and applications in general.

According to projections, freshwater availability will be a critical issue in the upcoming decades for different regions of the world. It is estimated that by 2050, about 40% of the global world population will be affected by severe water shortage, especially in parts of Africa and Asia, (Oecdobserver, 2012). The estimated increase in global water demands by 2050 would be about 55%, mainly due to industrial needs (manufacturing) in the amount of 400% and due to electricity generation (with included domestic use) reaching about 270%, (Oecdobserver, 2012). There is a high demand for the development of highly efficient freshwater generation systems and technologies, especially ones with assumed seawater desalinisation. An investigation of the operating parameters regarding freshwater generator capacities and system performances was discussed in (Yuksel et al., 2019). An energy and exergy analysis was applied together with the provided parametric study. The Taguchi method was used to maximise freshwater production and minimise exergy destruction rates in the main system components (condenser and evaporator). The results revealed specific operating conditions that can lead to the improvement of overall system efficiency. A novel biomass-based integrated system was proposed in (Safari and Dincer, 2019) capable of multi-generation, with assumed freshwater generation. The overall efficiency of the proposed systems is about 63% with a freshwater generation of 0.94 kg/s. The main fuel for the multi-generation system is biogas produced from digestion processes. The system is promising, however, requests further investigation of the economic suitability. The effect of saline water mediums (such as pure saline water, still water and saturated sand) on freshwater productivity of modified and convectional solar still was addressed in (Hassan et al., 2019b). A performance analysis related to freshwater productivity was obtained for different periods of the year. According to the results, the maximal efficiency of daily freshwater generation ranged from 13.8% (winter) to 15.3% (summer) for a wire mash and sand saline water modified system. It was also detected that the produced freshwater cost is reduced with the application of sand and wire mesh. Advanced and highly-efficient solar steam generation systems for enhanced water evaporation was proposed and addressed in (Miao et al., 2019).

A membrane distillation device was developed with carbon Nanotube and qualitative filter paper with aerogel blankets included. The thermal conversion efficiency of the system was about 84.6% and the examined solution turned out to be effective for seawater desalination. However, its economic aspect should be further investigated. The techno-economic evaluation of linear Fresnel reflector plants with integrated membrane distillation systems was discussed in (Soomro and Kim, 2018). The conducted analysis revealed that the considered analysed distillation system was able to achieve evaporation efficiency up to 50%, with an average freshwater generation of almost 32,000 L/d. The LCOE was found to be 0.34 ¢/kWh, with a specific water production cost of $\$0.425/m^3$. The proposed system showed reasonable performance with low unit production costs. Based on the latest existing addressed research findings, significant efforts are focused on investigations related to efficient freshwater generation systems based on the utilization of renewable energy sources.

The role of hydrogen in energy transition is considered to be important in specific applications with respect to the assumed mix of energy technologies. Further improvement of the economic viability of hydrogen-based technologies is necessary. The application of hydrogen is intensively and widely investigated from many aspects (Parra et al., 2019), where one of the main challenges in the field is related to hydrogen production methods with respect to their suitability and efficiency in the long term. A comprehensive review of large scale clean hydrogen production methods was provided by (El-Emam et al., 2019a). Recent progress in hydrogen production methods was presented and discussed with the focus being on techno-economic aspects. According to findings, it is necessary to ensure lower electricity prices from nuclear or geothermal sources to be able to compete with fossil-based hydrogen production when large scale hydrogen production is considered. Solar or wind-based technologies are highly sensitive and can strongly affect hydrogen production costs. Hydrogen fuel production from renewable biomass carbohydrates was thoroughly addressed in (Sharma, 2019) for different types of catalysis. The study stressed that cell-free synthetic pathway biotransformation showed to be the most suitable economic potential for hydrogen production regarding the considered application. Open issues related to biotransformation based hydrogen production is costly infrastructure, distribution and storage issues. Different challenges related to solar-based photocatalytic water splitting hydrogen production methods were discussed in (Guo et al., 2019). The study was mainly dealing with energy and mass flow perspective. The study revealed that several factors have important impact on the hydrogen generation efficiency such as the general design of a sunlight receiver system and general mass transfer in the system. The potential application of hydrogen is in the case of fuel cell hybrid electric vehicles (Yue et al., 2019), but there are still open issues related to the degradation of PEM (Proton Exchange Membrane) fuel cells and generally high production cost when compared to other market available vehicle technologies. It can be concluded that investigations in the field of hydrogen technologies are progressing in many technical aspects and assumed applications. Further research efforts are necessary for this field to ensure the preconditions for an economically viable hydrogen-economy and solve the main technical barriers related to storage, safety and efficient hydrogen production methods and infrastructure.

Retrofit approaches in specific individual processes and especially industrial applications are valuable to achieve targeted reduction in energy consumption and improve the economic and environmental suitability of different technologies or processes, (Liew et al., 2014). The implementation of the Pinch Methodology (PM) is an important and valuable tool in order to provide more efficient energy systems or components and improve sustainability in general. A new direction has thoroughly been discussed and primarily focused on the implementation and general importance of the PM (Klemeš et al., 2018) for various applications. A detailed analysis of possible approaches that could be used for the retrofitting of existing heat exchanger networks (HENs) was elaborated in (Čuček et al., 2019). Retrofitting approaches were discussed as well as optimisation approaches that can be divided into deterministic and stochastic, Fig. 22. Based on the conducted analysis, different future challenges were detected, identified and discussed such; as the development of more efficient software tools, efficient combination of process modifications, efficient application of a process integration methodology, real-time optimisation, etc. The conclusion of the study is directed to the necessity for the development of hybrid approaches combined with more efficient software tools.

A novel framework for circular integration of processes, industries and economies was discussed in (Walmsley et al., 2019). The framework was developed based on the insights from the industrial sites and processes integration. Air and marine transport were analysed to demonstrate the efficiency and importance of the proposed approach. A heat integration method (multiple heat exchange interfaces) was discussed in (Bütün et al., 2018) as a combination of mixed integer programming and Heat Integration. The proposed novel method was applied in two specific industrial case studies, where the apparent benefit of the developed approach was proved since according to the obtained analysis, it was possible to

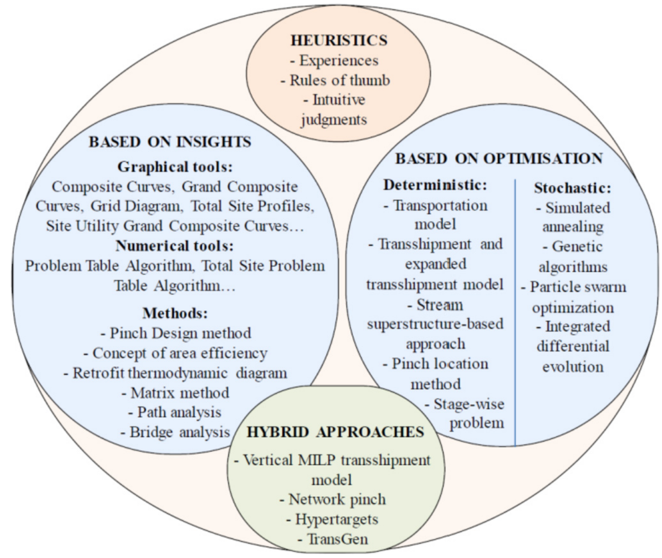

Fig. 22. Sketch of possible approaches for retrofitting existing processes and Total Sites (Čuček et al., 2019),

reduce the total cost of the system by 45% in the first case study. In the second case study, the heat load distribution was reduced by 78% as results of optimal selection. The developed methodology can help during retrofit processes as an effective tool. The integration of industrial parks as an opportunity for the reduction of total annual costs for retrofit was discussed in (Zhang et al., 2018) for the case of industrial parks run by natural gas. A total site analysis was provided for the considered case with deterministic global optimisation. The results showed that with energy retrofit, it is possible to ensure the payback time in less than two months, for specific measures, with a reduction of hot utility by 30.5%. The Time Super Targeting (TST) methodology was proposed and discussed in (Boldyryev et al., 2017) to discover optimal solutions in the retrofit process. A few case studies were addressed and analysed to demonstrate the effectiveness of the proposed methodology. Process Integration methodologies as well as also Total Site approaches are being intensively investigated as useful methodologies that can ensure the reduction of cost and harmful impacts on the environment. According to the latest research outcomes, there is still space for improvement with respect to the different possible case studies, with the main future challenges focused on the development of efficient hybrid approaches, followed by advanced software solutions that should enable highly-efficient optimisation in real-time.

The efficiency of load forecasting methods is a crucial feature to ensure efficient demand response management (Mohammad Rozali et al., 2016) and to be able to efficiently integrate renewable energy technologies in various applications. An analysis of several regression tools for the forecasting of urban electric loads was discussed in (Johannesen et al., 2019). The regression approach was obtained on a continuous time basis, with a vertical time axis approach while considering meteorological circumstances. The proposed approach turned out to be effective for short term prediction (30 min), with the application of random forest regression tools. For long-term prediction, other regression tools can provide better results. The proposed regression methodology can also be useful for the prediction of energy output from intermittent renewable energy sources. A simplified but flexible forecasting method for the short-term forecasting of heat load was proposed by (Nigitz and Gölles, 2019). The method is based on linear regression where the heat load is correlated with ambient temperature for each hour of the day. Method found to be efficient for the regulation of hybrid energy systems based on renewables. The impact of stochastic forecast errors associated with renewable generation as well as load demands on general micro-grid operations was addressed in (Chen et al., 2019). The novel models for the determination of stochastic forecasting errors concerning the operational stability and state of charge were proposed.

Specific impacts related to the service lifetime of the units was also addressed and discussed. A novel and smart energy management algorithm was developed for the load forecasting of island power systems in (Chapaloglou et al., 2019). The developed model is interesting since it integrates load forecasting methodology (pattern recognition) with a custom and optimal scheduling algorithm for the power. With the application of the developed forecasting algorithm, it was possible to ensure a more efficient penetration of renewables into the grid. A detailed review related to the application of forecasting models in renewable energy power systems was provided in (Ahmed and Khalid, 2019). The review was obtained for different applications such as optimal over system dispatches, energy market policies, generation scheduling, etc. Based on the conducted review, one of the main challenges is to determine optimal and precise forecast models with respect to the economy of the system and specific planning aspects. A real-time energy management system for a smart community micro-grid was elaborated in (Yan et al., 2019), with an assumed battery swapping and application of renewables. The proposed approach turned out to be efficient for energy scheduling and suitable for real-time applications. The overall economy of the considered renewable energy system could be improved. Considering the previously addressed latest research findings, it can be concluded that progress in efficient load forecasting exists, however, more case studies should be addressed and new advancements are generally necessary to provide more flexible and efficient load forecasting methods.

Besides the already previously addressed importance of globally installed PV capacities, wind capacities also play an important role in energy transition with a constant rise in installed units (Solar Power Europe, 2018). Investigations related to the improvement of existing wind turbine technologies are mandatory to improve their economic aspect and general market suitability from some other aspects (environmental and safety). The wind share effect on the aerodynamic performance, as well as electricity production, was analysed in (Ghazale et al., 2019) for the case of horizontal axis wind turbines. Blades were designed using the blade element momentum theory (BEM) together with a calculation of aerodynamic coefficients along the blade length. Based on the obtained results, it was found that the wind share effect does not have a significant effect on the aerodynamic coefficients in the root region (most changes occurred at 20%–80% of blade length, where wind turbine coefficient was generally reduced). The proposed analytical method increased the accuracy of the BEM method. A novel design of a deflector integrated cross axis wind turbine was reported in (Chong et al., 2019). The performance analysis of the specific design was carried out through simulations, and the concept showed reasonable potential in practical terms since it allows more efficient operation in circumstances of low winds, or highly turbulent wind flow conditions.

The investigation of vertical wind generators has become more intense in recent years due to their specific advantages when compared to horizontal turbines. However, existing technology still needs to be improved, especially in the blade design and novel materials to become more resistant to fatigue issues. Performance analysis of a Savonius vertical axis wind turbine was elaborated in (Manganhar et al., 2019), where the turbine was coupled with wind accelerating and guiding the rotor house. It was found that the introduced rotor house causes improvement regarding rotor coefficient with a factor of 1.74. The impact of oil temperature on the efficiency of the wind turbine gearbox system was reported in (Sequeira et al., 2019), where different oils were tested. The oil temperatures were measured for different loads as well as their effect on active power production. It was found that mineral oils are better for wind turbines than synthetic oils and the correlation was found between oil degradation and oil temperature. A concept of a small wind turbine equipped with flexible blades (morphing blades) was investigated in (MacPhee and Beyene, 2019) as an effective engineering design to increase the flexibility of existing turbines, with respect to variable operating conditions. The experimental results revealed that a flexible blade design enables more power output than the rigid ones, with an increase in the power coefficient by over 32% and operational range by over 34% for the considered cases. The previously addressed recent research studies prove that there are different technical possibilities for the improvement of existing wind generation technologies.

The energy efficiency improvement of the industrial sector is very important along with the building and transportation sector since some branches of the industry have high energy demands with significant impacts on the environment. An efficient production route analysis, with respect to the lowest energy consumption, was addressed in (Unver and Ozlem, 2019). AMPL software was used to simulate production efficiency and to analyse the specific process in the production route, Fig. 23. According to the conducted analysis, it was possible to achieve energy efficiency savings in the amount of 65% per unit production, with a proper correction of the production routes. The conducted analysis revealed that it was possible to achieve energy efficiency savings in the production process without direct investment in the production process.

Application of the neural networks together with the neuro fuzzy inference system was addressed in (Kaab et al., 2019). Approach was used to predict life cycle environmental impacts as well as energy output for the case of the sugarcane production. Results showed that largest impact on the sugarcane production have electricity consumption, machinery, biocides and stem cuttings. A routing strategy based on an improved A-star algorithm was proposed and discussed in (Balaji et al., 2019) for a case when the deployment of a receiver station was guided together with a ground support team, in circumstances when a suspended base robot was used in transmission line inspections for industrial applications. The proposed algorithm was tested in one segment of the transmission line in the State of Missouri (USA). The reported results revealed that a noticeable improvement in performance was achieved when compared to traditionally used inspection methods. Improvements were achieved in economic aspects, with reduced costs of about 8%, and also in environmental aspects, with a reduction of over 20% (when the proposed algorithm is compared to ad-hoc routing algorithms). An analysis directed to comprehending knowledge related to the energy intensity change in China's food industry was presented in (Xie and Lin, 2019). A comprehensive decomposition method was used to analyse energy intensity variations. The highest impact on the reduction of energy intensity has technological progress (reduction of about 70%) and improvement of energy efficiency (18.4%) and governmental policies. More investment in the research and development of novel technological solutions in the food industry is needed and coupled together with effective and strict governmental regulations during the planning stage. A novel simulation tool was developed and presented in (Gadaleta et al., 2019), suitable for the optimisation of industrial robot energy consumption. The proposed solution allowed automatic computation of the energy-optimal motion parameters and enabled an energy consumption reduction. A simulation approach was tested on an industrial robot and the

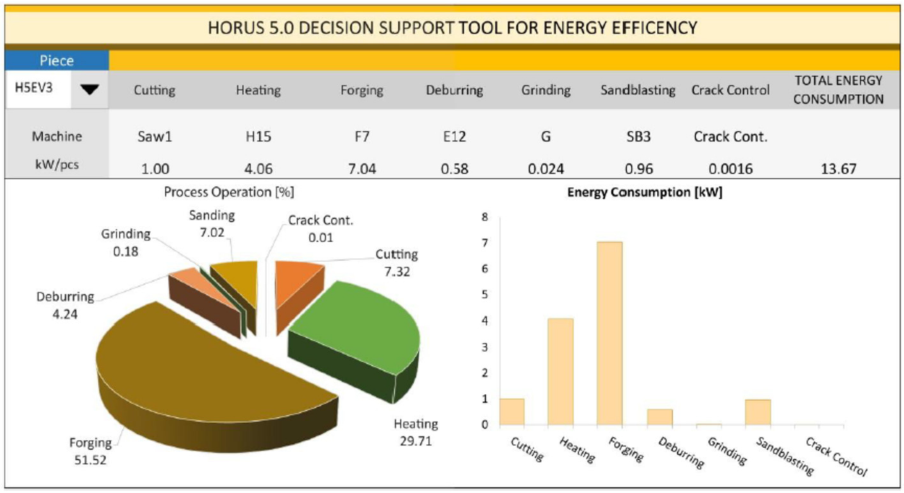

Fig. 23. Screenshot of used simulation software (Unver et al., ' 2019).

effectiveness of the method was proven. The economic aspect of the proposed approach was not addressed. A lean energy-saving concept was proposed in (Cai et al., 2019b) as a tool for the improvement of energy efficiency and reduction of harmful emissions from the manufacturing industry. The novel concept was applied to an industry case study and showed to be an effective tool to enable a sustainable manufacturing industry. A detailed study related to the cement industry was obtained in (Kermeli et al., 2019) and mainly focused on strategies for possible improvements regarding energy efficiency and reduction of greenhouse gas emissions (through the implementation of integrated assessment models). The importance of retrofitting was discussed as well as the issue associated with the reduction of the clinker to cement ration. Different energy scenarios were simulated with respect to the estimated energy intensity in the cement industry and released an amount of GHG emissions.

The efficiency of various technologies, processes components in energy systems is an important research topic with significant impact on sustainability and utilization of the limited resources. Selected latest advancements are briefly addressed; however, a more detailed review is needed in this rather wide research field. An investigation of gear ratio effects on exhaust emissions as well as fuel consumption was elaborated and discussed in (Umut Karagolan et al., 2019). A specific parallel hybrid construction was analysed that was equipped with a combustion engine and electric motor. Five different gear ratios were analysed through a developed simulation model using Matlab® software (version 9.4). The analysis provided the best combination of gear ratios that caused lower fuel consumption as well as reduction of CO_2, CO, NO_x and HC emissions. The highest achieved reduction in fuel consumption was about 17% with around 9% reduction in CO_2 emissions. Performance differences (fuel consumption as well as specific emissions), between hybrid and conventional vehicles, were addressed in (Huang et al., 2019b). The main idea of the research was to check fuel consumption in realistic circumstances when compared to the laboratory results. The field results revealed that both hybrid and convectional vehicles had considerably higher fuel consumptions than in the laboratory results. It was also found that pollutant emissions were lower with respect to regulation standards, but hybrid vehicles had higher CO emissions and no reduction in HE emissions compared to emissions from convectional vehicles (according to authors, a possible cause could be frequent stop and start of hybrid vehicles). An analysis of internal combustion and electric motorcycles was elaborated in (Weber de Assis Brasil et al., 2019) with the main emphasise is on the comparison of their energy performances. The dynamometric results showed that electric motorcycles are more energy efficient when compared to internal combustion motorcycles. The analysis was conducted for the Brazilian market, and it was found that battery impacts on the environment should be better investigated to get the overall aspect related to electric motorcycles. Future transportation systems will be organised as a mix of different transportation technologies with the associated economic and environmental impacts. In (Rocco et al., 2018), a hybrid approach (input-output analysis) was proposed as an evaluation framework to analyse the impact of transportation technologies with LCA (Life-cycle assessment) evaluation framework. The analysis of LCA and wheel to wheel approaches were compared, and considerable differences exist when the two mentioned frameworks are applied. It was also found that the impact of infrastructure and vehicle production facilities have significantly reduced CO_2 emissions. An energy efficiency analysis of a wet compressor system was obtained in (Abhay et al., 2019). A parametric study was conducted considering different influential parameters (air relative humidity, overspray percentage of water droplets, droplet diameter, etc.) to check the overall performance of the compressor system and its impact on system efficiency. It was found that the examined wet compression can cause an increase in the system's energy efficiency; if a small droplet diameter is ensured, together with larger overspray's in circumstances of lower compression speeds. They emphasized that the general control over the droplet dimensions and compression speed will be critical features from a practical point of view. An improvement of steam turbine stage efficiency was analysed in (Shibata et al., 2019) with an enabled control of the rotor shroud leakage flow. Based on the conducted CFD analysis, it was found that the stage efficiency could be improved from 0.2% to 0.7% with the proposed swirl breaker since it reduces mixing losses and improves incidence angles. Evaluation of flow losses and their impact on the performance of organic Rankine cycles was discussed in (Sun et al., 2019) with R245fa as the working fluid. It was found that the flow losses for the considered case can cause irreversibility in the evaporator and condenser. Flow losses ranged from 14% to 37%, with a maximal 17% decrease in thermal efficiency. From the addressed research papers, it is clear that there is a broad spectrum of possibilities for efficiency improvements in different engineering technologies to enable the more efficient use of existing technologies, systems and processes in general.

Waste issues have become a critical population feature with a necessity for effective approach circular economy framework, i.e. to achieve a desired zero-waste society (Türkeli et al., 2018). The main critical features related to waste issues have already been addressed in the introductory section with the emphasis being on plastic waste issues, food-waste, electronic waste and their unfavourable long-term impacts on the environment. The second major issue related to the waste issue is related to the energy consumption as well environmental impacts associated with the recycle systems for municipal solid waste, (Nabavi-Pelesaraei et al., 2017). Efficient waste management strategies and firm actions are needed for the proper implementation of the circular economy concept (Sabki et al., 2019). Waste should be apprehended as a valuable resource, where different possibilities for waste utilisation (recycling options) should be explored more intensively. The investigation of different waste potentials and recovery technologies for different processes is mandatory to ensure the desired sustainable goals.

The application of abundant residue in heat and electricity sustainable production processes, with an enabled production of the digested substrate (fertiliser) was reported in (Bedoic et al., 2019). The chemical characterisation of residue grass was obtained with a laboratory batch of mono and co-digestion tests. The gained results showed that reasonable digestive parameters could be achieved, with a low amount of impurities (which means that biogas from residue grass could be a viable option). A conducted life cycle analysis showed that residual grass is perspective for electricity and heat production when compared to maize silage. Synthesised ionic liquids were analysed in (Ullah et al., 2019) to examine how the extraction of specific but useful chemicals from sustainable rice husk waste and that affects the general properties of two ionic liquids. An ultraviolet technique, magnetic resonance as well as thermogravimetric analysis and high-performance liquid chromatography was applied to investigate the properties of the ionic liquids. The silica was successfully isolated from the examined biomass which could finally lead to the more efficient utilisation of rice husk in different industrial applications. The recycling possibility of phosphorus from incinerated fly ash (or sewage sludge) with the addition of biomass was reported (Zhao et al., 2019). The experimental results revealed that phosphorus bioavailability is improved with the proposed addition of biomass fuel.

The development of novel recycling possibilities should be followed by the promotion of sustainable consumption and production. Waste generation is significantly affected by recycling behaviour, which can vary from the type of specific economy. Waste management behaviour issues were addressed in (Minelgaitė and Liobikienė, 2019) for the EU region. The study stressed the general lack of knowledge amongst the EU population to understand the relationship between waste reduction and resource efficiency. The education of the population is mandatory to increase individual awareness and understand the contribution of individuals to the global waste problem. Recycling has a key role in smart waste management and different recycling possibilities have been investigated in recent years and some of them are addressed in Table 1. Based on the provided overview, the latest research findings are clearly focused on recycling and significant efforts are being made to solve issues with different kind of waste (plastic waste, electronic waste, polymer waste, etc.), where the main goal was to turn them into useful resources (materials) for different potential engineering applications (novel constructional materials, regeneration of valuable metals, hydrogen production, etc.).

A brief review of recent research findings in this section indicates that efficiency is still a crucial and challenging research task, since recent progress in that widespread field is clearly visible and directed explicitly to the efficiency analysis of systems, individual components or processes (freshwater generation systems, BEM systems, renewable energy technologies, industrial retrofit, etc.). The efficiency of transportation systems is progressing well, different techniques and approaches are being investigated towards the reduction of harmful pollutants into the environment caused by the utilisation of existing market available vehicle technologies. However, the focus should be directed towards the development of future transportation systems as an expected mix of transportation technologies (novel clean transport technologies with efficient utilization of renewables). Efficiency in industrial applications is also progressing where further development of Process Integration methodologies and Total Site approaches is needed through mainly advanced software solutions and hybrid approaches. More research efforts should also be directed towards the development of efficient demand response management strategies and general load forecasting methods as an important precondition for the efficient integration of renewable energy technologies in various applications. Waste management is mainly directed towards the investigation of novel recycling possibilities, which is visible from a wide number of recently conducted research studies. The investigation of the environmental suitability of novel recycled materials as well as analysis of economic aspects is missing in the majority of conducted studies and future research work should be addressed regarding these raised issues.

5. Smart cities and the Internet of Things

Connecting anything to the Internet regardless of its size is the main concept of the Internet of Things (IoT), where regular objects interact with their surroundings, and can be remotely supervised by users (Atzori et al., 2010). The IoT concept is applicable to various areas, such as agriculture, industry, healthcare, smart cities, security, nano-grids, etc. The global market share in recent years of IoT technologies with subsectors is presented in Fig. 24, with projections for 2020 regarding the expected market size, Fig. 25. Possibilities for technological developments through smart technologies are extensive, but critical approaches also need to be addressed to enable the sustainable and gradual implementation of IoT technologies (i.e. to investigate environmental impacts of smart technologies).

Specific technological solutions based on IoT technologies are challenging and futuristic in some aspects (gesture control armband, smart farming, smart eye, etc.), but some solutions are already close to the wide market applications. With such applicability, the number of Internet-connected devices is rapidly increasing and could reach more than 34 milliards by 2025 according to response predictions, which means a significant rise in IoT infrastructure.

Without a doubt, the economic impact of IoT markets will be significant, especially when compared to saturated markets such as smartphones, (Al-Turjman, 2019). In the near future, the overcome of several technical issues related to the application of IoT technologies should be bridged such as power consumption, energy efficiency, connectivity, processing power, device to device (D2D) communication, infrastructure and many more (Asghari et al., 2019). These issues are amplified in densely populated areas such as smart cities that would host most of the IoT devices, and perform data collection through sensors, supplying information that will aid in distributing various resources in a more efficient manner (Zedadra et al., 2019). Smart cities would demand great infrastructure due to unprecedented data that needs to be generated (Gharaibeh et al., 2017), representing a big market, especially for advertising companies. The data related to connected devices can reveal the hidden patterns in user habits that are not normally captured by browsing the Internet after it is processed through techniques, such as Big data (Ang et al., 2017).

Table 1
Overview of the latest selected investigated recycling possibilities for various applications.

Reference	Recycling waste	Application/Remarks
Singh et al, (2019a)	Ployethylene gloves	Hydrophobic coating application
Zhao et al. (2019)	Waste biomass	Phospor recovery from fly ash from the industrial sewage sludge.
Seghar et al. (2019)	Natural rubber industry waste	Investigation of the physical properties after extrusion process
Singh et al. (2019b)	Coal bottom ash	Concrete aggregates blended with metakaolin
Mir and Pandey (2019)	Waste plastic	Hydrogen production
Hossain et al. (2019b)	Demolished bricks, fly ash and rice husk ash	Production of green building bricks
Luhar and Luhar (2019)	Electronic waste	Application in constructional industry
Park and Kim (2019)	Waste printed circute boards	Extraction of metals
Wang et al. (2019b)	Sapphire kerf waste	Purification application
Kale and Gorade (2019)	Medical cotton waste	Production of self reinforced composites
Yang et al. (2019b)	Lithium-ion battries	Graphite regeneration
Siddique et al. (2019)	Ceramics waste	Concrete production
Ebin et al. (2019)	Household battrie waste	Extraction of valuable metals
Okan et al. (2019)	Waste ploymer	Different application
Saccani et al. (2019)	Carbon fiber/epoxy composite waste	Production of composites
De la colina martinez et al. (2019)	Electronic waste	Concrete production

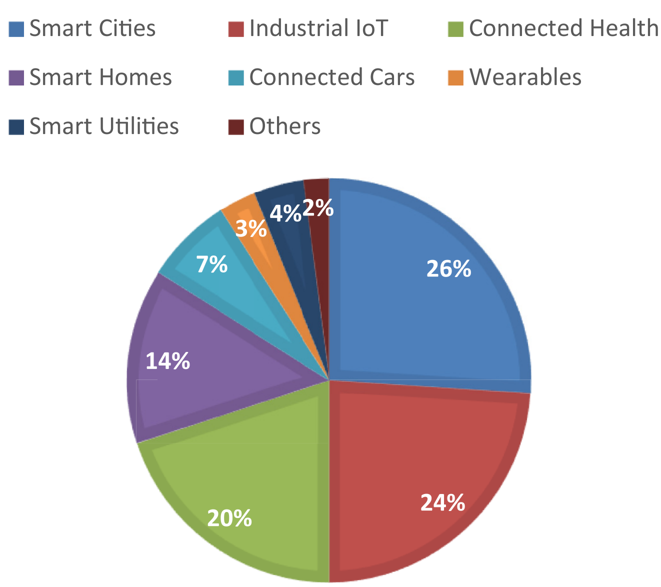

Fig. 24. IoT technologies for different applications (Forbes, 2017)

It is foreseen that smart cities will not only hold most of the IoT devices but also most of their users and applications, solving several issues related to modern cities, Fig. 26. The main idea of the smart city concept is to provide more efficient services (better organisation) in cities, to improve safety, enable a general quality of the environment in cites for work and living. Smart transportation systems could increase user comfort, security, reduce traffic jams by providing drivers real-time data regarding traffic reports, rerouting traffic and adjusting speed limits based on this information (Neto et al., 2018).

Moreover, drivers will no longer search for vacant parking spots because of smart parking solutions that enable them to visualise this information in real-time through their smartphones (Lin et al., 2017). Waste management could become more effective due to available techniques, giving cities a cleaner look (Pardini et al., 2019a, b). Security, safety and privacy will also play a huge role with modern cities possessing various CCTV cameras that can identify potentially hazardous situations in real-time, as well as the perpetrators. The users will gain in security and safety but the trade off their privacy. Device management will also be a challenge because it will be impossible for people to individually manage every device, so could certainly rise, which means that IoT devices

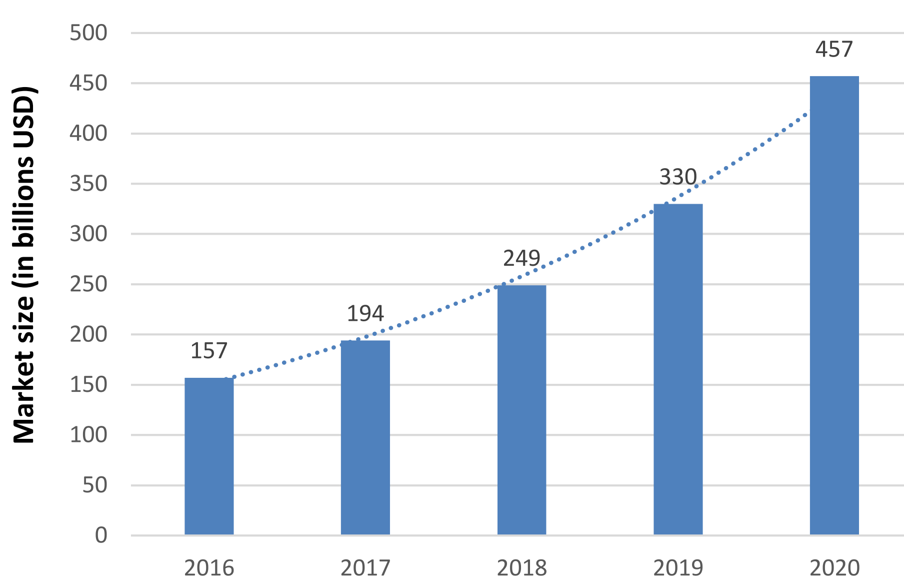

Fig. 25. Market size of the IoT technologies, (Forbes, 2017).

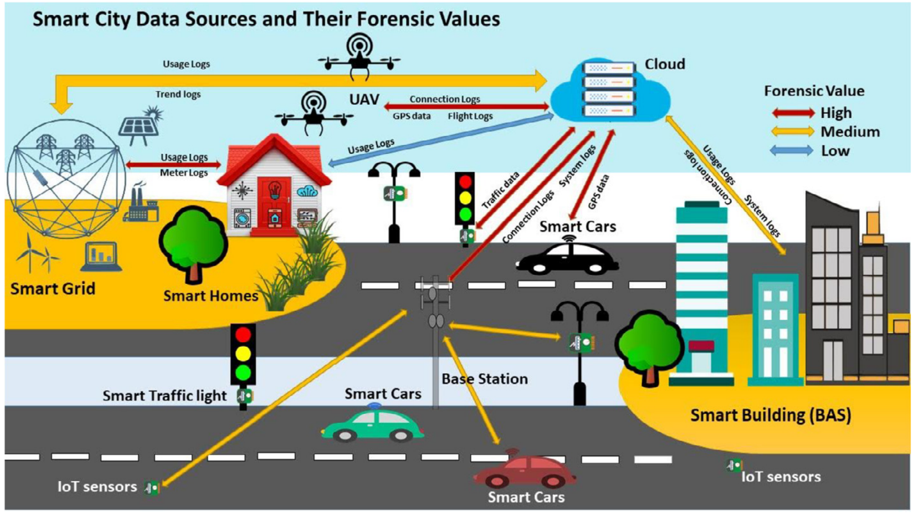

Fig. 26. A sketch of the Smart city concept (Elsevier, 2019)

must be energy efficient or self-sustainable to reduce their impact (Deakin and Reid, 2018). With the rise of IoT applications, a rise in specific resources for electronic equipment could be expected and a general increase in e-waste. With the increased data traffic representing such a big issue, pre-processing the data sent by devices might be vital, (Tang et al., 2018). These data are going to be transmitted wirelessly where various options are available and can range from traditional cellular networks to specific IoT methods, such as LoRa, SigFox, NB-IoT, 5G, etc. (Oliveira et al., 2019). For data consulting with an IoT user (human, applications or devices), it must be stored in an IoT Middleware platform that needs to be secure, robust and which allows third-party applications to be built on top of it (da Cruz et al., 2018a). An exhaustive performance evaluation should be made to determine the scalability of the chosen middleware solution in scenarios with various concurrent users. While pre-processing, data mostly focuses on minimum, maximum and average values whereas post-processing is generally based on more sophisticated techniques, such as big data or even artificial intelligence where the context of transmitted data could change its interpretation (da Cruz et al., 2018b). A brief review of the latest research results from this progressing thematic are provided in the continuation in this review paper and directed towards specific applications and issues (smart grids, smart city, smart transport, smart waste management, smart agriculture, etc.).

One major issue is related to the distribution and transmission efficiency of smart data which is usually obtained through optical networks, Fig. 27, i.e. efficiency of smart grids. A strategy aiming to improve network agility and automatization was proposed in (Xu et al., 2019b) and based on software-defined networks and function visualisation. Novel routing applications have been developed using the OpenFlow protocol. The proposed solution turned out to be effective and feasible on a semi-practical platform demonstration.

Bi-directional energy flows between the smart grid, and wind energy prosumers were incorporated into a developed model. Presented results proved further contribution to the development of stochastic energy management models for the efficient integration of renewables in smart grids. A review article related to energy metering in smart grids was provided by (Danielly et al., 2019). The main challenges related to smart metering were discussed to ensure fully functional and security-aware smart grids, Fig. 28. A detailed description of the main smart meter functionalities was provided and discussed in relation to the general

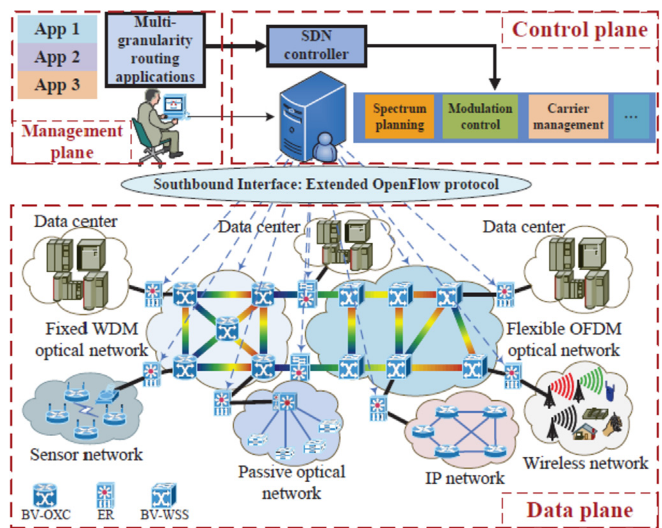

Fig. 27. Software architecture for multi granular inter-DC optical networks (Xu et al., 2019b).

technical capabilities of smart meter market available technologies. The main step towards further development and more efficient utilisation of smart meters will be through the application of the IoT concept (more efficient sensing and measurement). The implementation of smart sensing through IoT technologies could lead to the automatization of energy measurement, i.e. more efficient response and real-time decisions. One of the major challenges is to develop novel and smart detection systems by the gradual development of IoT structures in smart homes.

The development of a smart and sophisticated control and data acquisition system for optimisation, control and monitoring of drinking water systems was reported in (Mkireb et al., 2019). The developed smart demand response approach turned out to be an efficient solution in an examined real case study in France. The proposed system showed flexibility underwater demand uncertainties and would be useful to check the effectiveness of the developed model for other case studies in different countries. The literature review focused on automated approaches for disease vector mosquitoes, monitoring was reported in (Santos et al., 2019).

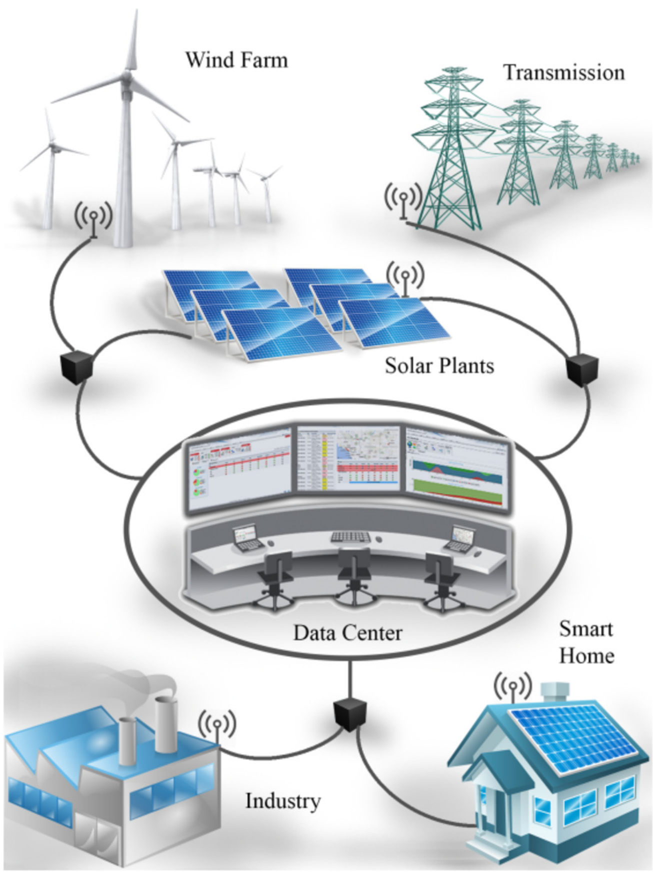

Fig. 28. Smart grid perspective (Danielly et al., 2019).

The main research outcome was directed towards the identification of further research opportunities in that specific area considering new data processing as well as the application of transmission emerging technologies. In order to ensure the further progress of monitoring approaches, the new technologies are needed with an emphasis on Machine Learning, Big Data and Internet of Things. The application of optical sensors was also addressed as a key feature in insect-borne disease surveillance. A smart grid framework for the stochastic wind energy management was discussed in (Hussain et al., 2019). A bi-directional model was applied between smart cities and wind energy prosumers. The developed model was found to be an effective tool for non-linear stochastic price modelling, i.e. an energy management modelling strategy suitable for the smart city concept. A novel lightweight context-aware IoT service architecture was proposed in (Prasad et al., 2019), i.e. the LISA approach to support IoT push services in a more efficient manner. The main concept of the LISA approach is to formulate a user model that would resolve local decision making while using agents and web service paradigms. For the model, a performance analysis of an IoT tourist guide system was analysed as a case study. The simulation results revealed that the LISA could reasonably reduce information distributed to the users with a selection of the most relevant among them. The proposed method can be further optimised with fine tuning (user-specific settings) and the improvement of the query processing time as well as query generation time. Smart control algorithms were addressed in (Pallonetto et al., 2019) for demand response approaches in the residential sector. A simulation model was developed to analyse smart demand response strategies concerning different electricity tariffs and thermal comfort conditions. According to the case study obtained for typical residential facilities in Ireland, the possibility to reduce electricity costs was proved as well as reduction of the utility generation costs and carbon emissions. The optimisation of a smart energy network system for Canadian communities was discussed in (Ghorab, 2019) to minimise energy costs and reduce GHG emissions. The study was conducted on twenty Canadian buildings with an enabled exchange of thermal energy and electricity. The optimization model provided possibilities for a reduction in electricity costs and GHG emissions, where the integration of PV systems (with enabled battery storage) lead to the highest reduction in GHG emissions. The importance of smart grid optimization was demonstrated since it was possible to improve both economic and environmental aspects. A comprehensive review focused on demand response modelling, and smart algorithms were delivered in (Vázquez-Canteli et al., 2019). The conducted review directed that the majority of published papers are focused on single-agent systems and stationary environments. The need for education on multi-agent systems should be provided in the next step. Further challenges and possible research directions were also examined in the mentioned paper.

Smart mobility (transportation) in smart city concepts represents a significant challenge to enable a smart and efficient journey. The application of Big Data technologies can help to ensure efficient management of vehicles that are treated as nods in the network. An Ant colony optimisation (ACO) approach was applied in (Lakshmanaprabu et al., 2019) for the routing of vehicular networks. Based on the obtained simulations, it was concluded that it is possible to achieve a significant reduction in the node count rise (Hadoop framework case). The future development of the proposed approach should be directed towards the hybridisation of ACO algorithms, with some metaheuristic algorithms. Two-hybrid adaptive bandwidth and power algorithms (HABPA) with Delay-tolerant Streaming Algorithms (DSA) were proposed by (Hassan et al., 2019c) to enable a more sustainable smart city platform. The experimental approach considered an analysis of the performance metrics, power drain, battery lifetime, delay, etc. According to the experimental results, it was possible to optimise the power drain and battery lifetime (about 37%). The main contribution of the proposed HABPA approach for media streaming through an IoT-based smart city is the battery lifetime extension which is more than important from a sustainability point of view. Excessive application of electric vehicles, followed by the necessary development of infrastructure, will have a significant impact on electricity generation structure. The previously mentioned problem was discussed in (Taljegard et al., 2019) as a case study for Scandinavian-German market circumstances. The electricity generation capacities by 2050 were addressed where a cost-minimisation investment model was applied together with an electricity dispatch model. The analysis showed the importance of careful transportation system planning with respect to the development of renewable energy capacities. A gamified survey approach was considered in (Lara et al., 2019) to investigate how the population value electric vehicle (EV) charging services, i.e. how willing they are to pay for EVS charging services (goal was to provide insights on willingness). An evaluation approach was applied through a conventional questionnaire combined with a game-based questionnaire. The main goal was to solve the issue related to data collection regarding EVs, since data are usually unavailable or difficult to reach from the existing EV-related datasets (general nature of available data). The gamified questionnaire showed to be more efficient when compared to text-only questionnaires and have increased design complexity as well. The proposed approach showed to be especially efficient for cases when it was difficult to extract real-world data. It was also found that EV owners are ready to pay less if the state charge is high and users are generally ready to pay higher prices if the electricity price is known. In any case, the developed and demonstrated approach contributed to a better understanding of influential parameters for EV owners related to payment willingness, for EV charging, and insight will help to develop an efficient and innovative sustainable business model. The social impact of future autonomous vehicles was discussed in (Marletto, 2019). Specific social-technological impacts were discussed in future terms such as the integration of suppliers to ensure components for automated vehicles, a collaboration between the leaders and managers of transportation systems, the impact of innovators, etc. Autonomous vehicle transportation systems will cause specific social impacts on society and they need to be further investigated. New challenges and possibilities for the development of smart grids were discussed in (Monteiro et al., 2019) with respect to vehicle electrification. Issues related to current electrical power girds were discussed and the general necessity for a more flexible adaptation in dynamic environments. Further progress in the development of power electronic systems was also found to be a critical feature towards efficient smart grids in transportation systems. More intense research work is needed in the field of smart transportation systems.

The implementation of smart and IoT technologies in the field of security has become significantly interesting for different surveillance purposes (e-health, smart homes, management systems, etc.). A novel framework for the efficient emergency management of critical events and incidents was proposed in (Manar et al., 2019) for smart cities. The proposed framework uses text mining, text classification, named entity recognition and stemming techniques. The data are automatically collected from social media and processed to generate intelligence reports. The results were collected from Arabic tweeter with an achieved classification accuracy of more than 96%. The developed approach turned out to be a more efficient tool in emergency situations through better coordination and planning of specific rescue situations and protocols. Issues related to the application of IoT technologies for healthcare purposes were addressed in (Panchatcharam and Vivekanandan, 2019). The application of IoT technologies towards smart healthcare services was discussed; current issues such as the main benefit related to the application of smart technologies through improvement of healthcare administration. The concept of a novel cost-effective smart home sensor was reported in (Davidson et al., 2019) as a useful technical gadget to improve home security. A smart home sensor has the task to inform the user via an Android application in the case when doors are opened in home environments (or office applications). The potential application of the developed sensor was discussed and its technical issues that need to be solved, such as interference with other radio frequency devices. The possible application of IoT technologies in real stores or marketplaces was addressed in (Chojnacki and Rykowski, 2019) for behaviour control and monitoring of activities (but also for other applications in stores such as HVAC control, etc.). The implementation of IoT technologies could lead to the development of different market tools to enable more efficient business in the considered applications. Fog computing has the potential for different applications and services since it can enable cost reduction and increase effectiveness in general. The implementation of fog computing in the analysis of surveillance videos in smart cities was discussed in (Nasir et al., 2019). The novel and efficient framework was proposed and based on fog computing. The proposed approach showed good potential for cloud solutions with effectiveness for IoT supported smart cities. The monitoring of different defence activities for staff with the application of IoT technologies was reported in (Bhatia and Sood, 2018). Daily activities, social engagement and other aspects that can represent a threat to national security have been collected via IoT based data collection systems. The developed approach could be a useful tool to analyse the behaviour of defence personnel and to detect potential risks from a safety point of view.

Smart agriculture has become an emerging field where IoT technologies could be implemented in an effective way and help make agriculture more sustainable and economically viable. A comprehensive review related to the application of IoT technologies for precise agriculture was provided by (Khanna and Kaur, 2019). Future research directions have been discussed for the improvement of IoT technologies and present critical issues linked with the efficient application of IoT technologies in agriculture. A smart agriculture monitoring system for the detection of soil temperature and moisture was presented in (Mekala and Viswanathan, 2019). The proposed cloud-based solution can ensure the efficient monitoring of specific crop comfort levels and could be an accurate and effective decision tool for farmers with a reported accuracy of 94%. A case study for a solar pumping system monitored via the application of IoT technologies was reported in (Sirisamphanwong et al., 2019) for Thai smart farming. Specific technical IoT based smart solutions were discussed that were based on real application and gained experiences and contributed to the concept of smart farming. Results of the study could be useful for other similar applications. IoT technologies can also be used for smart irrigation in agricultural purposes, which can contribute to environmental sustainability. A concept of a smart water management approach for an efficient water irrigation system in agriculture was reported in (Kamienski et al., 2019). The specific architecture of the proposed management system was discussed, and the major concern is found to be in the necessity to redesign some components in the system to enable high stability followed with less computing time. An analysis focused on the effective application of IoT technologies in the case of cotton farming was reported in (Khan et al., 2019). The study focused on the architecture design of different IoT solutions with the application of cotton farming (cultivation, irrigation, harvesting, etc.). An IoT based framework was proposed, and it could lead to smart farming for the considered case.

Further, development directions of IoT technologies for smart agriculture were discussed in (Lakhwani et al., 2019). Different benefits linked with the application of IoT technologies in agriculture were discussed, i.e. the already investigated technical applications and potential for improvements. The possible prediction of strawberry disease with the application of Iot technologies for smart farming was reported in (Kim et al., 2018). A cloud-based technology was elaborated for the collection and analysis of data and prediction of possible scenarios in strawberry farming.

IoT devices were applied together with the development of an IoT-Hub network. The developed smart monitoring system proved to be efficient as a prediction tool for the control of disease occurrence in strawberry farming. A smart system for bicarbonate control in irrigation processes was reported in (Cambra et al., 2018) to enable precision farming. The developed smart solution enabled the control of pH nutrient levels in hydroponic agriculture. An auto-calibrated pH sensor was used connected to a wireless node and enabled a web monitoring interface that can be reached with a computer or smartphone. The concept proved to be efficient for the considered purpose, i.e. effective technical approach for smart control of nutrients during the irrigation process.

Smart waste management could be further advanced and upgraded with the implementation of IoT technologies. The smart waste management concept in future smart cities was discussed in (Marques et al., 2019) from a long-term perspective. The necessity for intelligent services and their development in future smart cities were discussed as well as the importance of IoT technologies. Waste management was addressed via a case study regarding a specific concept, i.e. technical solution that can handle 3902 garbage bins in a simultaneous manner. The proposed garbage bins can separate organic and recyclable waste. The concept of a smart waste management system capable of separating different types of waste was proposed in (Kansara et al., 2019). A specific smart bin prototype can alert garbage collector services when the bin is filled to 80%. The strategy for efficient collection of filled bins is also developed to save fuel for garbage trucks and to reduce the harmful impacts on the environment. The garbage truck is assumed to have a robotic arm for the segregation of different types of waste. The literature review focused on the implementation of IoT technologies with respect to the smart waste management approach was provided in (Pardini et al., 2019a, b). Current smart based efficient strategies for waste management were discussed focused on the urban environments. An IoT based model was developed to provide a comparative analysis and detect technical issues that need to be solved to enable more efficient smart waste management. A smart trash monitoring and segregation system were presented in (Dhyani and Patel, 2019) using emerging technology. An effective approach related to the proper management of municipal waste through different stages was discussed and followed by the utilisation of IoT technologies (smart water detection, smart trash segregation and smart garbage collection). Innovative techniques related to the previous aspect were addressed, which were based on a conducted literature survey. An efficient and smart approach for residential garbage collection under smart city concepts was discussed in (Rossit et al., 2019). A case study of a mid-sized Argentinian city was analysed with examined garbage bin locations, selection criteria. The main goal was to improve the quality of service and to reduce costs by the smart waste management system. The developed model demonstrated that an effective door-to-door garbage collection system with community bins could be provided. The study (Anagnostopoulos et al., 2018) addressed the issue related to smart waste management regarding bins and trucks with the application of IoT technologies (i.e. sensors and actuators). The focus of the research was on dynamic scheduling in stochastic conditions for different seasons of the year in two years. The problem was solved with a multi-agent system applied for stochastic analysis and turned out to be a quality solution for the considered purpose. A stochastic optimisation framework was developed and discussed in (Jatinkumar Shah et al., 2018) for the smart management of waste in smart cities. The main target of the provided optimisation was to reduce costs and to consider the quality of waste that can be recovered from the collected waste. The developed numerical model can help for the smart planning and collection of waste with the assumed application of acquisition technologies. The model can also monitor the level of recyclables included in each trash bin.

Recent advancements in the application of smart technologies supported by the IoT concept showed that potentials for improvements are high, especially within the smart city framework.

Different smart technical solutions are discussed in various applications, with the main focus being on enabling efficient and cost-effective smart technologies on the market. It was also noticed that the studies did not address the environmental impacts of specific IoT technologies, i.e. sustainability in general. Future research directions should be focused on the environmental and economic evaluation of smart technologies. Investigations of novel technical solutions should be enabled to integrate existing sensor technologies into useful products for the population. Final benefit of the smart technologies should lead to cost-reduction, improved quality of service and contribution to environmental protection.

6. Concluding remarks

The world is rapidly progressing through the 21st century and is turning into a more challenging and complex system, especially from the sustainability point of the view. The rapid growth of population, along with the urbanisation and the development of more than 30 mega-cities by 2020, is at the same time the result and the driving force of socioeconomic and technological changes, as we are moving at an unknown pace, with long-term effects on population and environment. Against this background, the analysis and optimisation of single and partial problems are of course important, and it is a prerequisite, but is not sufficient, as interdisciplinary knowledge is needed, to achieve the sustainability goals which are a ‘sine qua non’ to ensure the population's survival into the 22nd century. This review paper was focused on recent advancements in the wider spread field of smart technologies to provide a foundation for the two main axes of sustainability, namely efficient conversion of resources and rational waste management, through the implementation of the smart technologies.

In order to achieve this, review editorial was compiled selected papers that were presented at the 3rd International Conference on Smart and Sustainable Technologies (SplTtech2018), held on 26–29 June 2018 in Split (Croatia) at the University of Split. Additionally, an overview of recent research studies was carried out, to highlight the progress in the field and to obtain a deeper insight into current advances on specific topics.

From the findings of the conducted review, specific and useful conclusions can be derived in the fields of energy efficiency, novel energy technologies and the applications of smart and IoT technologies. Recent works in the area of energy thrifty and environmental friendly buildings focus on the implementation of the NZEB concept and the effective integration of renewable energy technologies (RES) in buildings, based on experimental investigations and field case studies. Innovative thermal insulation materials and techniques are widely investigated for the improvement of the building envelope's energy performance, the targeted reduction of thermal bridges and the improvement of thermal comfort conditions. Another critical aspect is the effective demand-side management and the successful integration of different RES technologies into the NZEB concept, to be able to transform buildings from energy users to energy producers. Recent progress in solar energy utilisation is directed towards the further improvement of PV technologies available on the market as well as investigations of novel PV technologies, with Perovskite based technology being the most promising one for the upcoming market application. Efficiency improvement and further development of control strategies for PVs and for management of hybrid energy systems were also discussed.

Further points of interest are silicon-based PV technologies, such as cooling techniques for PVs, cleaning strategies for PVs, more precise regulation techniques for MPPT, etc. All those actions will lead to more feasible silicon-based PV technologies, which is important since they are expected to dominate the market for the coming decade. The application of PV/T technologies can contribute to increased overall efficiencies and utilised roof areas, which is always a commodity in short supply. Still, considerable research efforts are needed to improve the cost-efficiency ratio of PV/T systems. Similarly, research progress is also monitored in the development of CPV systems, where different concepts and ideas were discussed to overcome some present technical barriers and to reduce both the investment and operational cost of CPV technology.

Considering energy efficiency beyond the building sector, research results are discussing case studies for different engineering applications, systems and processes, including renewable energy technologies, freshwater generation systems, fuel cells, steam turbines, compressors, etc. One thing common in all these applications, is the margin for further improvements, especially to improve efficiency in the industrial and transportation sector, both of which are energy intensive. Yet again, the importance of process integration methodologies was underlined, with further necessary advancements towards more efficient hybrid solutions supported by more efficient software tools.

Waste management is a key issue towards sustainability and a wide research area. The problems of plastic waste, especially of micro-plastics, food waste and electronic waste are in the focus of the research community and are inexorably linked with the stability of the ecosystems. Different recycling possibilities were being intensively investigated to enable smarter use of precious resources and a reduction of waste production. One point that emerges is the need to promote the circularity in the economy, a most promising approach which can ultimately address the resources and waste problems at the same time. However, there is a lot of research work that needs to be done, both on the methodology and its development via successful case studies.

The last thematic area within this VSI was dedicated to the smart city concept and the application of smart technologies supported by IoT technologies. In a sense, the smart city concept provides the framework for the implementation of all the mentioned technologies, yet at the same time, it cannot be considered as the simple summation of their results but is rather their integral. There is a significant growth of studies and research publications addressing the application of smart technologies and their incorporation into products. Recently investigated smart concepts are focused on several topics: smart city's framework, smart metering, smart transportation, security, smart agriculture, smart waste management, etc. Smart technologies are considered as an opportunity for cost reductions, a tool for the improvement of service quality and a way to achieve the reduction of environmental impacts. The way into the future leads probably along two routes. The first is the intensification of research focused on the potential application of smart technologies that can improve life quality, especially in urban areas, from air quality to public transportation for instance. The second is the improvement of the cost-effectiveness of smart technologies, which will provide a boost for their propagation. A finding met in most publications is that more case studies are needed, to demonstrate these factors to convince the public and the stakeholders of the benefits that can be achieved.

Economic growth, improvement of living standards and the development of society, in general, has an environmental cost, which has become apparent that it is leading to a distortion of natural balance. It is anthropogenic activities that cause to a great extent the problem, and it has to be human interventions that will provide solutions. Sustainability is a goal that is not illusionary, but it presupposes a vision, carefully planning of targeted actions and their timely and effective implementation. Novel technologies need to be critically evaluated, to fulfil complex requirements that will enable a balanced and sustainable future. The herein addressed contributions will hopefully help to obtain a better insight and understanding of causative consequences, technological potentials as well as threats regarding specific technologies, processes and products. The topics addressed are truly widespread, and this paper should have served its purpose if it has provided highlights that should act as an impulse and a guide for further and more targeted research by the scientific community.

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