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A review of developments in technologies and research with a direct measurable impact on sustainability considering the Paris Agreement on Climate Change

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Abstract

This special issue of Renewable and Sustainable Energy Reviews is devoted to the research presented and discussed at the 10th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES) held from the 27th September to the 2nd October 2015 in Dubrovnik, Croatia. The contents are in keeping with the aims and scope of the journal which is to bring together under one roof the current advances in the ever broadening field of renewable and sustainable energy. However, Conferences on Sustainable Development of Energy, Water and Environment system, and associated dedicated special issues, have gathered a significant amount of knowledge in these fields and can give a deeper insight into the direct measurable impacts on sustainability. The articles published in this special issue, together with other SDEWES special issues create a synergy that review, discuss and examine energy resources and technologies (e.g. biomass, hydropower, solar, geothermal and wind), applications and services (e.g. buildings, industry, electricity and transport) and policy and the environment (e.g. economics, emissions, politics, energy planning, social aspects) within the framework of sustainable development, which is very timely considering the Paris Agreement on Climate Change in 2015. A total of 35 extended manuscripts were invited by the guest editors of this special issue for consideration for publication in Renewable and Sustainable Energy Reviews. After a vigorous review process by expert reviewers in their respective fields and overseen by the guest editors a total of 22 articles were accepted for publication.

Keywords

Renewable energy, sustainable development, biomass, hydropower, solar, geothermal, wind, buildings, industry, electricity, transport, policy, environment, emissions, economics, social aspects, politics, energy planning, climate change

List of abbreviations

AD = anaerobic digestion

AHP = analytic hierarchy process

AHP = analytic hierarchy process

BEM = Building Energy Modelling

BIM = Building Information Modelling

BOD = biological oxygen demand

BRE = Building Research Establishment

CHP = combined heat and power

CO₂ = carbon dioxide

COP = Conference of the Parties

CP = Coefficient of Performance

EIA = Environmental impact assessments

ENSC = Nash-Sutcliffe model efficiency coefficient

ESI = Energy Security Index

ETS = emissions trading scheme

EU = European Union

EV = electric vehicle

GHG = greenhouse gas

GSH = ground source heat

HAWP = high altitude wind power

LDMI = Logarithmic Mean Divisia Index

LIES = Locally Integrated Energy Sector

LQG = linear quadratic Gaussian

MENA = Middle East and North Africa

MILP = mixed integer linear programming

ORC = Organic Rankine Cycle

PAD = pressurised anaerobic digestion pps = pervious paving systems

PV = photovoltaics

RES = renewable energy sources

SDEWES = Sustainable Development of Energy, Water and Environment Systems

SWOT = strengths weaknesses opportunities and threats

TEC = thermo-ecological cost

TRL = technology readiness level

UK = United Kingdom

UASB = Upflow Anaerobic Sludge Blanket

ZEB = zero energy buildings

1.0 Introduction

The 10th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES) held in Dubrovnik, Croatia from the 27th September to the 2nd October 2015 was hot on the trail of the United Nations Climate Change Conference or COP 21 held in Paris where 195 world leaders met to consider the Paris Agreement on Climate Change, which aims to limit global warming by significantly decarbonising human activity in a three pronged approach that combines efficiency, self-sufficiency and renewable energy in order to preserve the planet and humanity [1]. The Paris Agreement recognises the urgent need for finance, technology and capacity-building by developed countries to enable developing countries to deploy renewable energy and thus guarantee sustainable energy. One of the key conclusions is that combating climate change and securing sustainable development requires a multi sectorial and interdisciplinary approach and actions. This is one of the cornerstones of the series of Conferences on Sustainable Development of Energy, Water and Environment Systems. At SDEWES scientists and engineers from all over the world gather to discuss various technology and research, society and policy, in an interdisciplinary setting to share and gain a deeper understanding of key sustainability challenges. The main dissemination tool of SDEWES conferences are the dedicated special issues which are published in some of the most prestigious international scientific journals, dealing with energy and sustainability. The last SDEWES conference, held in Dubrovnik 2015, had in total 541 contributions, with 22 of these, presented in this special issue of Renewable and Sustainable Energy Reviews, having an important role to play in mapping the pathways to local, regional and ultimately global decarbonisation by informing key decision makers from industry and government of the findings of cutting-edge research and the state-of-the-art of existing and novel technologies in the field. The guest editors have a diverse background, expertise and knowledge in the field of sustainable energy including biofuels [2], [3], [4], wind [5], [6], [7], [8], [9] solar photovoltaics [10], [11], [12], [13] electric vehicles (EV) [14], [15], [16], [17], [18] greenhouse gas (GHG) emissions [19], [20], [21], [22], [23], electricity markets [24], [25], [26], [27], energy storage [28], [29], [30], [31], [32][33] and climate change measures [34], [35], [36], [37]. As academics and researchers in the field of sustainable energy we should aim to analyse the complex interaction of technology in terms of environmental costs, energy costs, energy security and economic opportunity to fully decarbonise human activity and preserve the planet. This interaction has recently been referred to as the ‘energy quadrilemma’ [38], [39], [40], [41].

The aim of this editorial is to briefly review the knowledge learned in the 22 articles published in this SDEWES special issue that have can have direct and indirect impacts on sustainability considering the Paris Agreement. Since this special issue also covers some interesting aspects of the ‘energy quadrilemma’ an extensive literature review of previous SDEWES special issue articles have included to utilise all the generated knowledge, create linkage and to emphasise the integration and interdisciplinary aspects of the research. The key findings of the articles in this special issue dedicated to SDEWES are summarised under the following topics: i) renewable energy resources and technologies (e.g. biomass, hydropower, solar, geothermal and wind), ii) decarbonisation of buildings, industry, electricity and transport and iii) case studies, policy and the environment (e.g. economics, emissions, politics, energy planning, and social aspects).

2.0 Renewable energy resources and technologies

Renewable energy resources and technologies have a critical role to play in achieving our challenging energy and GHG emissions reduction targets. However, in order to appreciate the role that these resources and technologies can play the capabilities, costs and technology readiness levels (TRL) of these must be understood. From the beginning, one of the main research focuses of SDEWES conferences were renewable energy sources (RES) and their integration into different energy systems. Now, fourteen years after the first SDEWES conference, we can say that clean energy systems, based on renewable energy resources are both technically and economically viable [42]. As a result of this, future energy systems need to change and integrate cross-sectorally (e.g. electricity, heating/cooling, water management and transport) in order to satisfy the paradigm in which the demand is following variable supply, in comparison to today’s system where supply is following the demand. Maybe the most interest among SDEWES contributions, through all these years, can be attributed to solar and wind energy. When it comes to wind energy research, contributions have went from purely technical and design solutions, like innovative approach to the analysis of diffuser augmented wind turbines [43] or linear quadratic Gaussian (LQG) controllers for fatigue loads reduction [44], to policy and integration problems, which were probably the most represented. Authors have analysed specifics of wind power plants integration into transmission networks [45], arbitrage potentials as a mean of increasing wind penetration [46] and long term off-shore wind potentials in comparison to national energy targets [47]. When it comes to solar energy, researchers have been focused on analysing policy measures and non-technical barriers for higher PV integration [48] and the influence of Feed in tariffs on PV cost and geographic distribution [49]. Integration of solar energy (both PV and solar thermal) has also been a very active topic among SDEWES contributors. The synergies between PV pump hydro energy storage in rural dry areas has been analysed [50], as well as the potential utilisation of low temperature heat through the Organic Rankin Cycle (ORC) for solar domestic applications [51].

The ORC was particularly interesting in the utilisation of geothermal energy as well. In [52] authors are analysing basic and dual-pressure ORC with the implementation done on a specific geothermal plant, as a case study. One of the prerequisites of geothermal energy utilization is the creation of quality geothermal maps, which was the focus of [53], where neural networks were used to determine potentials at three different depths. Beside electricity generation, geothermal energy was also investigated as a low temperature heat source for district heating. In the case of Frederikshavn, geothermal heat, in combination with absorption heat pump paves the road to a 100% renewable city. A 100% renewable energy systems were an often focus of SDEWES conferences contributions. In many cases these efforts and analysis went beyond city or regional scales and analysed whole countries (Ireland [54], Japan [55], Macedonia [56] and Denmark [57]). Some of the research presented at SDEWES conferences included work on establishing, developing and evaluating energy analysis tools. The importance of the transport sector and its integration in the overall energy system has been discussed and shown in previous studies [58] as has the possibility to utilise advanced modelling techniques such as agent based modelling [59]. In [60] the difficulty in simulating non-automotive (e.g. forklifts) and non-highway (e.g. inner-city buses) vehicles is reviewed and the tools available to undertake such simulations are outlined. The key finding is that non-automotive and off-highway drivetrain simulation may require bespoke models involving both commercial (e.g. AVL Cruise, AMESim, Dynacore etc.) and software such as MATLAB/Simulink. Biogas, another renewable energy resource, has the potential to decarbonise energy systems. Previously, policy support to overcome techno-economic barriers of biogas utilisation and effects of different biogas distribution strategies were investigated in [61]. Two potential sectors for biogas use are covered and the results show that relatively low subsidies give significant increases in cost-effective biogas utilisation levels, although for full technical potential to be exploited, high subsidies are still needed. In [62] the decarbonisation of a power utility portfolio as a function of RES and decarbonisation goals proposed a novel method of power generation portfolio optimization, along with appropriate criteria.

A further study [63] demonstrated the economic viability of larger biogas plants and the high impact transport has on these larger plants in rural areas. According to new research in [64] biogas can utilise the potential to decarbonise energy systems 'only if its lifecycle carbon dioxide (CO₂) footprint is lower than that of displaced conventional technologies, which is sometimes uncertain.' This research on biogas also noted that the typical life cycle CO₂ footprint of biogas ranges from 50 to 450 kgCO₂/MWh_{el} based on an in-depth review of the published academic literature and found that pressurised anaerobic digestion (PAD) based biogas plants produce higher purity biomethane with a much lower direct CO₂ footprint of 13kg/MWh_f (where f means footprint of biomethane) based on a case study involving six plant configurations compared to conventional combined heat and power (CHP) systems with a direct CO₂ footprint of 700kgCO₂/MWh_{el} (where el means footprint of electricity). Previously, the mathematical approach for improving the reliability of parameter

calibration in modelling of anaerobic digestion (AD) processes has been investigated in [65], where the modified Nash-Sutcliffe model efficiency coefficient (ENSC) was used to assess the quality of simulations compared to observed data from the mesophilic mono-fermentation of grass silage. An alternative approach using an Upflow Anaerobic Sludge Blanket (UASB) reactor was investigated in [66] for the treatment of wastewater with biogas production. On a similar topic, [67] overviews feed control methodologies of (AD) processes for renewable energy production of biogas. The review concluded that although many sophisticated controllers exist most full-scale biogas plant operate using a closed-loop feed control, and that the most sophisticated controllers were found at anaerobic wastewater treatment plants, whereas the least sophisticated controllers were found at agricultural and industry based AD plants due to a conservative approach that avoided online instrumentation for process monitoring. An assessment of sustainability guidelines of the European Union (EU) RES Directive was given in [68] for the case of bio-refineries. An exergy analysis [69] was performed to evaluate the alternatives for microalgae oil extraction. In [70] third generation biofuel technologies such as algal-based biorefineries are proposed as a sustainable alternative to first generation food-based biofuels due to ‘the food-versus-fuel debate and indirect land-use change emissions’. However, there remains much debate on the techno-economic problems faced by biofuels produced from algal-based biorefineries, which is in part due to the different research methodologies employed in the published studies. This in-depth review article examined sixty-four environmental studies, forty economic analyses and twenty studies to provide a qualitative-based assessment of algal-based biorefineries to establish a generic environmental techno-economic methodology to streamline LCA to reduce time-to-market for new sustainable technologies.

In [71], the first microgrid being developed in the Western Balkan region serves as pilot site for introduction and examination of microgrid concepts in non-EU conditions. A community microgrid and consumer demand response was used to utilise demand–supply matching in [72]. Adaptive controls using integrated mixed integer linear programming (MILP) were used in [73] to assess the flexibility benefits of microgrid systems and operational costs savings were demonstrated. [74] provides a systematic review of published research on the environmental and economic impacts of smart grids. This in-depth and detailed study highlighted the inconsistency in the methods used, the underlying assumptions and results, and recommended that ‘there is a need to develop and test a framework for cost-benefit assessments’ of smart grid systems. New novel technologies are also assessed in this SDEWES special issue. High altitude wind power (HAWP) is an attention-grabbing technology. So far, the physical concepts supporting the implementation were demonstrated in [75], which showed a theoretical feasibility of the Magnus’ effect as a concept for harvesting high altitude winds. Also, the costs, size, and durability of energy storage systems for a HAWP application were investigated in [76]. A solution for construction using a variable-length tether was elaborated in [77], describing the shape, forces and vibrations of the tether. A techno-economic analysis of HAWP in

Northern Ireland determined a total viable optimal land area of 5109.6km² with ‘an average wind power density of 1998 W/m² over a 20-year span, at a fixed altitude of 3000m’ and calculated a preliminary budget cost of approximately £1.75 million for a 2MW pumping kite device [78].

3.0 Decarbonisation of buildings, industry, electricity and transport

The electrification and decentralisation of heating, cooling and other energy loads in buildings and industry is another piece of the puzzle on the roadmap to societal decarbonisation. There are many developments and activities on-going globally that are taking different technologies in isolation and in combination to reduce the energy and GHG emissions footprint of society. When it comes to heating and cooling, shifting towards nearly zero energy buildings (ZEB) require new low temperature solutions. As a main decentralised solution, capable of serious primary energy savings, heat pumps are identified. For example, in [79], opportunities for exploitation of open-loop groundwater heat pump are presented. Energy analysis of the system shows that ground-water heat pumps constitute an interesting option in areas with small housing density. In [80], results of an optimal design process were presented for a ground-source heat pump system including thermal modelling of the system and selection of optimal design parameters which affect the system performance and operational costs. In [81] combined ground source heat (GSH) pervious paving systems (pps) and rainwater harvesting is reviewed and unpublished data from the ‘Hanson Ecohouse’ on the Innovation Park at the Building Research Establishment (BRE) in Garston, Watford in the United Kingdom (UK) is described. The key findings of the work are that the Coefficient of Performance (CP) based on a literature review of such combined systems is viable and can reach the 2.875 which meets the EU RES Directive [82]. Small-scale laboratory testing indicated that a combined GSH pps rainwater harvesting system reduced the pollutants (i.e. 99% for biological oxygen demand (BOD) and 95% for ammonia-nitrogen); and not only does the combined system provide clean renewable energy it also provides flood mitigation.

Decarbonisation is based on the cross-sectoral integration of renewable energy as a substitute for fossil fuels, on one side and efficient usage of resources on the other. In that sense cogeneration and trigeneration plants present another valuable mean of utilising both RES and fossil fuels. Trigeneration systems and their thermo-ecological cost (TEC) for various fuels was investigated in [83]. A decision tool for trigeneration systems in buildings sector was demonstrated in [84] showing the optimisation of the plant lay-out, the sizes of the main components and their operation strategy for a hotel building. Similarly, in [85] micro-trigeneration for residential applications (i.e. heating, cooling and hot water production) are reviewed and tested on three multi-family houses in Palermo, Naples and Milan in Italy over a year using the transient simulation software tool TRANSYS 17 [86]. The results were then compared with a conventional standalone system and showed a reduced i) primary energy consumption (e.g. 4.3% in Palermo), ii) equivalent CO₂ emissions (e.g. 10.6% Milan) and iii) annual

operating costs (e.g. 11.3% Palermo). However, the pay-back period was only acceptable in Milan considering current economic incentives in Italy. Another technology that can reduce the energy use, costs and carbon footprint of buildings is shallow geothermal energy system. In [87] the use of geothermal energy in combination with an absorption heat pump was examined and shows promise for district heating application and reduction of fossil fuel consumption. A study of shallow geothermal energy systems in [88] summarised that the published research and compared the levels of deployment and regulatory requirements in six EU countries (i.e. Italy, Spain, Germany, the UK, France and Sweden). The correlation between deployment, research activity and the effectiveness and cohesiveness of EU regulations was also examined. Ironically, although Italy was one of the most active countries in terms of research, this did not translate into the regulatory requirements. Integrating different energy sources and sinks in systems is one way to decarbonise buildings, industry, electricity and transport. This can be implemented using different modelling approaches. In [89] a literature review of the state-of-the-art of Building Information Modelling (BIM) to Building Energy Modelling (BEM) for industrial facilities and a case study of adopting a BIM to BEM approach at two industrial facilities to enable more efficient life-cycle management is provided. In the conclusion the barriers and challenges to BIM adoption and the benefits of the BIM to BEM workflow in an industrial setting are identified. The utilisation of life cycle cost calculations has been discussed in previous research showing the need for its adoption and customisation [90] while the research conducted in [91] demonstrated a novel approach for building energy efficient automation, meaning the simulation and optimisation of energy consumption and better integration of energy systems on a building level. Another method to analyse energy optimisation and integration in thermodynamic systems and processes is the Pinch Analysis [92]. This method is widespread in process engineering and is usually utilised for the optimisation of industrial processes such as in [93], but its modifications can also be used in for example, the transport sector [94]. Here an extension of the Pinch Analysis is applied to 'industrial, residential, commercial, institutional and service energy systems' to maximise the incorporation and 'reuse of waste and low potential heat, including renewables to boost sustainability' in an approach called Locally Integrated Energy Sector (LIES) is overviewed in detail in [95].

4.0 Case studies, policy and the environment

Case studies on the success, challenges and impacts of renewable and sustainable energy projects are useful to inform society, industry and decision-makers on policy and environment plans on prioritising and implementing best practice in solving the 'energy quadrilemma.' In this SDEWES special issue a number of the articles identify some of the competing forces seen in the 'energy quadrilemma' using case studies. Previous studies have shown the possibility to assess the technical or economic potential for the utilization of certain technologies or energy sources in a given region, such as the potential for the utilisation of industrial waste heat in Croatia [96], the potential for the utilization concentrated solar power in Middle East and North Africa (MENA) countries [97] and photovoltaics (PV) in the

Canary Islands [98]. In [99] the potential for locating solar plants in the Esfahan province, one of the main industrial centres in central Iran is presented considering environmental, geomorphological, location, climatic and various constraint parameters using an analytic hierarchy process (AHP). The case study determined that 3.12% (or 3,339km²), 76.8% (or 82,189km²) and 11.9% (or 12,735km²) of the land area of the Esfahan province has excellent, good and valid surface potential to deploy solar plants. Brazil has been the focus of several previous studies such as the research conducted in [100] where the prospects for the utilisation of biofuels up to 2030 is investigated and [101] which deals with the possibility to utilize sugarcane biomass for power production. The objective of [102] was to qualitatively summarise the Brazilian electricity sector to 2030 considering uncertainties in energy usage, demand and development (e.g. smart grid, EVs, commercial and regulatory trends etc.) and consumer behaviour. The key finding is a series of guidelines to achieve the challenging 'Energy in Future City' scenario. The relation between the farming sector and energy has been discussed in previous research such as [103] where the potential for the utilisation of biogas was demonstrated and [104] where the use of agricultural biomass in CHP has been presented on a study for Serbia. In another case study [105] the effect of increases in electricity costs on 58 farming communities in north-eastern Spain are investigated and changes in the current tariff structure as well as increases in self-consumption are proposed to reduce energy costs and mitigate sector problems. The measurement of the success or failure of policies and technologies requires standardised metrics or indicators to allow a useful comparison by decision makers. In [106] a new energy security indicator with long-term sustainability is defined and tested on a sample of 28 EU Member States from 1990 to 2012. This indicator includes environmental and social aspects in the weighting of the index unlike other metrics previously used (e.g. Herfindahl-Hirschmann Index, Supply/Demand Index, Oil Vulnerability Index etc.). The study results indicated a positive trend overall in Energy Security Index (ESI) values, except in the case of former Eastern Bloc countries. Each of the main indicators have been studied in separate articles, such as energy intensity, with all the positive and negative aspects of using it [107]. Some research articles have analysed various parameters influencing energy development and have also defined a level of sustainable energy development, for example on a case study for Western Balkan countries [108]. Usually the analyses of various energy policy impacts are done for a specific energy policy measure and sector, such as industry [109], power sector [110], transport sector [111], buildings [112] etc. However, a study [113] used the Logarithmic Mean Divisia Index (LMDI) decomposition method to examine the effectiveness of sustainable development policy drivers in the energy sector in a cross-country comparison approach of three developed countries (i.e. UK, Portugal and Spain) and three developing countries (i.e. Brazil, China and India) and found that the LMDI decomposition method identifies the dominant factors in sustainable policy design. Case studies can also provide useful information to decision makers, industry and society on innovative technology deployment in terms of effectiveness and challenges. In terms of deploying new and innovative technology potential needs to be determined. In [114] the issue of waste palm cooking oil was analysed as one of the

important quests towards sustainable development. The disposal was analysed through an environment friendly route and was utilised as an alternative for refined vegetable oil. In [115] biomethanol production with endemic chenopod as a substrate was investigated. This specific endemic chenopod displayed strong productivity and adeptness, while the special focus of the research was on the specific yields per hectare.

In [116] the carbon sequestration potential of different biomass-to-energy techniques for agricultural residues in five countries in the Mekong River basin in Southeast Asia is examined using a regression model. The analysis calculated that the conversion of agricultural residues to bioethanol, biogas and co-combustion sequestered approximately 98TgCO₂, 161TgCO₂ and 488TgCO₂, respectively thus mitigating the carbon footprint of agriculture. Environmental impact assessments (EIA) and studies are widely used to ensure and support sustainable development, which often involves competing considerations and the safeguard of protected areas. Macchia Lucchese or the Pineta di Levante near Viareggio in Northern Tuscany in Italy is one such protected area and in [117] the strengths, weaknesses, opportunities and threats of connecting three campsites, the coast and the Regional Park of Migliarino, San Rossore and Massaciuccoli by a diesel-powered train or an electric train are described. In [118] a simple, but interesting multicriteria analysis was used to measure eco-innovation. Afterwards this was applied to the transport system in order to prioritise various actions so further assessments of these actions could be made. In [119] an accent on sustainability of rural tourism in Spain was created. The assessment was made, acquiring qualitative data through personal interviews with experts and a strengths weaknesses opportunities and threats (SWOT) analysis to answer the question of theoretical framework of sustainable tourism.

The complex interactions of the energy-water nexus are explored in [120] by optimising the role of desalination, water storage and 'airspace' at a small hydro dam in Sydney, Australia to meet three objectives (i.e. meet the city's water needs, mitigate flooding and generate electricity while buffering any floods). the gap between water supply and demand planning in relation to social and economic strategies is addressed, since no comprehensive life-cycle approaches on modelling urban water balances were present in [121]. A system dynamics model and applied to the south-east Queensland region in Australia in [122] to analyse ongoing strategies as a response to prolonged droughts in Australia, primarily through the expansion of the desalination plants. The focus of the research was in the context of a decision of a large desalination plant that could be built in Sydney. As a result, a disconnection between the key factors (planning process, community engagement and political decision making) was identified and analysed.

A case study of major policy measures for biofuels in passenger car transport across fifteen EU Members States found that although a CO₂ emission standard is important in reducing fuel

consumption and CO₂ emissions. It was found that this standard was alone not effective in the absence of accompanying policy measures (e.g. a CO₂-based fuel tax) considering increasing car sizes and vehicle km driven [123]. In previous research [111] various fuel intensity and effects on energy demand of passenger cars in the EU-15 was analysed. Special focus in this research was on the rebound effect and its influence on energy conservation due to changes in car size and fuel intensity. The main conclusion was that the various energy efficiency policies will have a limited effect if some kind of fuel taxation is not introduced. The focus of [100] was on GHG reduction potential through the implementation of biofuels in the transport sector. Another objective was to investigate long term market potential of biofuels till 2030 for the three most important markets; USA, EU and Brazil.

In 2014 the EU agreed a climate and energy policy framework [124] for 2030 that set three key targets to 1) cut GHG emissions by at least 40% from 1990 levels, 2) reach a 27% share in renewable energy and 3) improve energy efficiency by at least 27%. In [125] a thorough comparative analysis of untapped energy efficiency potentials in all 28 EU Member States indicates that despite the inadequacies in the database the goal of achieving a 27% improvement in energy efficiency by 2030 'appears to be quite feasible with high policy effort'. It is obvious that achieving these targets will require a cross sector efforts, primarily in the buildings, transport, industry and power sector. Numerous research have already been done sector wise. In [126] environmental taxation policy at the EU level was studied in order to measure its financial effects. In [127] energy efficiency improvements on the European building stock until 2050 was examined. Results have shown that the EU 2020 goals for primary energy savings could be met with a strong focus on 2% yearly efficiency improvements at useful energy level. In [128] the energy efficiency improvements in the EU building stock was also analysed, but in this case by extensive survey questioners. The main idea was to have a clearer vision on the current national frameworks. It is clear from the resaechr in this special issue that overall EU targets will be a combination of cross sector efforts. In [129] informational efficiency of the EU Emissions Trading (ETS) Scheme as a major part of the future efforts in levering GHG emissions and increasing overall energy efficiency was examined.

5.0 Discussion and conclusion

Research is clearly flourishing in the field of sustainability and renewable energy. The field is multidisciplinary due to the nature of the issues involved. Sometimes this can become a challenge and limit the exchange of ideas, particularly between practitioners (e.g. scientists, engineers, architects, town planners, lawyers, doctors etc.), society and policy makers, as silos can inadvertently grow. For example, silos can inadvertently develop amongst practitioners as students. This is investigated from the perspective of training engineering students in [130]. The study also refers to a longitudinal study [131] that questions the success of engineering education to foster engineers with a 'sense of professional responsibility to the welfare of the public.' This question could, of course, be posed to all

professions. Indeed, it could be further argued that social and environmental responsibility is learned at an early age from family, peers and the rest of society. However, those committed to the environment, reduced GHG emissions, renewable energy and eliminating energy poverty must keep positive. In [132] the focus is the challenges in engineering education, especially energy, in order to implement and amplify the role of multimedia in the learning process. In the work several issues are addressed from the basic skills and knowledge necessary for the students to the development of tools, methods or virtual libraries. In [133] it is argued that sustainability in engineering education needs to be addressed at meta-level using primarily a whole of system approach.

The research discussed and presented at SDEWES conferences shine a light on the interdisciplinary interactions, research and positive social conscious amongst researchers, society and policy makers. In conclusion, this SDEWES special issue edition of Renewable and Sustainable Energy Reviews gives just a small snapshot of the policies, technologies and environmental measures in place and proposed to decarbonise anthropogenic activities that demonstrate the growing social commitment and consciousness of society as a whole to preserve our beautiful planet.

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