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A review of developments in technologies and research that have had 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 2, 2015 in Dubrovnik, Croatia. The contents are in 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. The articles published in this special issue 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. economic, emissions, politics, energy planning, social aspects) within the framework of sustainable development. A total of 35 extended manuscripts were invited by the guest editors of this special to submit candidate articles for consideration for publication in Renewable and Sustainable Energy Reviews. After a vigorous review process by expert reviewers overseen by the guest editors a total of 22 articles were accepted for publication.

1. 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 Paris climate conference (COP21) 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, 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. The research disseminated at SDEWES and presented in this special issue of Renewable and Sustainable Energy Reviews has 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 biofuel [2–4], wind [5–10] solar photovoltaics [11–13], electric vehicles [14–17], greenhouse gas (GHG) emissions [18–22], electricity markets [23–26], energy storage [27–31] and climate change measures [32–35]. 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' [36–39]. 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 impact on

Abbreviations: 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; CP, coefficient of performance; EU, European Union; EV, electric vehicle; GHG, greenhouse gas; GSH, combined ground source heat; HAWP, high altitude wind power; LDMI, Logarithmic Mean Divisia Index; LIES, Locally Integrated Energy Sector; PAD, pressurised anaerobic digestor; pps, pervious paving systems; SDEWES, sustainable development of energy, water and environment systems; TRL, technology readiness level; UK, United Kingdom.

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sustainability considering the Paris Agreement on Climate Change. This special issue also covers some interesting aspects of the 'energy quadrilemma.' 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. economic, emissions, politics, energy planning, social aspects).

2. Renewable energy resources and technologies

Renewable energy resources and technologies have a critical role to play in achieving our reaching our challenging energy and GHG emissions reduction targets. However, in order to appreciate the role that these resources and technologies can play we must first understand their capabilities, costs and technology readiness levels (TRL). Some of the research presented at SDEWES included work on establishing, developing and evaluating energy analysis tools. In [40] the difficulty simulating non-automotive (e.g. forklifts) and non-highway (e.g. inner-city buses) is reviewed and the tools available to undertake such simulations is 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, Dynacar etc) and software such as MATLAB/Simulink. For instance, biogas another renewable energy resource has the potential to decarbonise energy systems according to [41] 'only if its lifecycle carbon dioxide (CO_2) footprint is lower than that of displaced conventional technologies, which is sometimes uncertain.' This article on biogas also noted that the typical life cycle CO_2 footprint of biogas ranges from 50 to 450 $kgCO_2/MWh_{el}$ based on an in-depth review of published academic literature and found that pressurised anaerobic digestor (PAD) based biogas plants produce higher purity biomethane with an extremely lower direct CO_2 footprint of 13 kg/MWh_f based on a case study involving six plant configurations compared to conventional combined heat and power (CHP) systems with a direct CO_2 footprint of 700$kgCO_2/MWh_{el}$. On a similar topic, [42] overviews feed control methodologies of anaerobic digestion (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 lest sophisticated controllers were found at agricultural and industry based AD plant due a conservative approach that avoided online instrumentation for process monitoring. In [43] third generation biofuel technology such as algal-based biorefineries have been 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 study methodologies employed in published studies. This article performs a review of sixty-four environmental studies, forty economic analyses and twenty studies that included both to provide a qualitative assessment of published material on algal-based biorefineries to establish a generic environmental techno-economic methodology to stream life cycle assessment in order to reduce time-to-market for new sustainable technologies. A further article in this SDEWES special issue provides a systematic review of published research of the environmental and economic impacts of smart grids [44]. This in-depth and detailed study highlighted the inconsistency in the methods used, 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. A techno-economic analysis of HAWP in Northern Ireland determined a total viable optimal land area of 5109.6 km^2 with 'an average wind power density of 1998 W/m^2 over a 20-year span, at a fixed altitude of 3000 m' and calculated a preliminary budget cost of approximately £1.75million for a 2 MW pumping kite device [45].

3. 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. In [46] 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 is 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 European Union (EU) Renewable Energy Directive [47], that the combined GSH pps rainwater harvesting system reduced the pollutant potential (i.e. 99% for biological oxygen demand (BOD) and 95% for ammonia-nitrogen) of pathogenic bacteria such as *Legonella* and *Escherichia coli* and that not only does the combined system provide clean renewable energy it also provides flood mitigation. Similarly in [48] 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 [49]. 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 CO_2 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 and costs and carbon footprint of buildings are shallow geothermal energy systems (e.g. GSH), [50] summarised 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 were 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 apaches. In [51] 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. Another method to analyse energy optimisation and integration in thermodynamic systems and processes is Pinch Analysis [52]. An extension of Pinch Analysis 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 [53].

4. 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. In [54] 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 3339 km^2), 76.8% (or 82,189 km^2) and 11.9% (or 12,735 km^2) has excellent, good and valid surface potential to deploy solar plants. The objective of [55] was to qualitatively summarise the Brazilian electricity sector to 2030 considering uncertainties in energy usage, demand and development (e.g. smart grid, electric vehicles (EV), commercial and regulatory trends etc.) and consumer behaviour. The key finding is a series of guideline to achieve the challenging 'Energy in Future City' scenario. In another case study [56] 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 success or failure of policies and technologies require standardised metrics or indicators to allow a useful comparison by decision makers. In [57] 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, which 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 values, except in the case of former Eastern Bloc countries. Another study, [58] uses Logarithmic Mean Divisia Index (LDMI) 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. For example, in [59] the carbon sequestration potential of different biomass-to-energy techniques for agricultural residues in five countries in the Mekong River basin in Southeast Asia are examined using a regression model. The analysis calculated that the conversion of agricultural residues to bioethanol, biogas and co-combustion sequestered approximately 98$TgCO_2$, 161$TgCO_2$ and 488$TgCO_2$, respectively thus mitigating the carbon footprint of agriculture. Environmental impact assessments and studies are widely used to ensure and support sustainable development, which often involve competing considerations and protection of protected areas. Macchia Lucchese or the Pineta di Levante near Viareggio in Northern Tuscany in Italy is one such protected area and in [60] 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. The complex interactions of the energy-water nexus is explored in another case study, [61] 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). A case study of major policy measures for biofuels in passenger car transport across fifteen EU Members States found that although a CO_2 emission standard is important in reducing fuel consumption and CO_2 emissions it alone is not effective in the absence of accompanying policy measures (e.g. a CO_2-based fuel tax) considering increasing car sizes and vehicle km driven [62]. In 2014 the EU agreed a climate and energy policy framework [63] 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 [64] 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 at 27% energy efficiency by 2030 'appears to be quite feasible with high policy effort'.

5. 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. scientist, engineers, architects, town planners, lawyers, doctors etc.), society and policy makers, as silos can inadvertently grow. For example, silos can grow inadvertently develop amongst practitioners as students. This is investigated from the perspective of training engineering students in [65]. The same article also refers to a longitudinal study [66] that questions the success of engineering education to foster engineers with '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. The articles discussed and presented at SDEWES shine a bright spot 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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