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Development in efficiency, cost, optimization, simulation and environmental impact of energy systems

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ABSTRACT

The conference series *International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems* – abbreviated ECOS has been at the forefront of the scientific development in energy systems for over three decades. 2018 saw the 31st edition of ECOS held in Guimarães, Portugal. The venue received the contribution of over three hundred papers ranging over 19 selected topics, covering aspects related to thermodynamics, energy systems integration and optimization, planning, cogeneration of heat and power, environmental issues, amongst others.

A number of the contributions were invited to the present special issue of the International Journal of Sustainable Energy Planning and Management, and eight of these were after the selection and reviewing process considered to bring the best contributions to the field. These articles address rural household appliance ownership, how much flexibility there is in the Bolivian electricity system to accommodate wind power and photo voltaics, national exergy analyses of Bolivia and thermal imagery of buildings to assess heat losses from these.

Other work focus on polygeneration system combining renewable energy sources, cogeneration of heat, cooling and power to supply district heating and cooling in a case area in Italy. In the same area, a mobile thermal energy storage using phase change material is proposed as a way to connect heat sources and heat demands. For the future electrification of the transportation sector and for system design, reliable data on driving cycles are required thus methods for assessing these are presented, followed by analyses of high penetrations of electricity in the transportation system through various technological options.

Keywords;

Appliance ownership;
VRES and exergy analysis;
Thermal imagery;
Polygeneration and heat storage;
Electric vehicles;

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1. Electricity demand assessment

The principal objective of energy supply is to improve of the quality of life, and this present a particular challenge if one considers rural communities in developing countries. The provision of energy – and here notably electricity – may be achieved through the dissemination of electrification projects. This however, requires accurate estimation of the households' energy demand for proper system design. In order to avoid on-site data collection Domingueza et al. [1] presents a methodology for modelling the appliance ownership of rural households in developing countries to project their electricity demand.

Based on data from more than 1,100 household samples from Nigeria and Ethiopia - the region with the lowest electrification rates in the world - the correlation between household survey data of ownership of the most common electricity-consuming appliances in developing countries and different socio-economic, demographic and geographic variables are investigated. Using multiple

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linear regression, the article investigates the number of electrical appliances owned by a rural household according to their socioeconomic, demographic and geographic characteristics, which can be used to calculate the electricity demand per household.

2. National energy systems

In managing power grids, the variability and uncertainty of renewable energy sources (RES) represent a major challenge. Power systems must cope with uncertainty and variability in the demand, and supply of energy. Candia et al. [2] evaluate the flexibility of the Bolivian interconnected electric system against a high share of solar-PV/wind-onshore technologies taking into account the characteristics of the Bolivian energy supply. The authors use the Dispa-SET tool developed for the European Union power sector that focuses on the short-term operation of large-scale energy systems by solving the unit commitment and energy dispatch problem. The study carried out shows that Bolivian electric system flexibility depends mainly on the response capacity of its conventional units (mostly gas thermal, and hydro-storage), and on the interconnections between its internal areas. Simulation results show that the power system in 2021 could integrate a much higher RES share than usually believed. The system has enough flexible resources to accept between 25–30% of variable renewable energy sources (VRES), which corresponds to about 964-1,240 MW of solar photo voltaics or 968-1,244 MW of wind-onshore capacity in the Bolivian electricity system.

Velasquez et al. [3] argue that economic models often take into account that resources are free and in most cases limitless. This leads to a growing scarcity of natural resources and a relentless rate of non-recoverable waste. The authors describe the application of 2nd law of thermodynamics to an energy performance analysis of Colombia by analyzing the exergy mix in the energy consumption over a span of 40 years. This is focused on the characteristic irreversibility of each resource and the estimation of the irreversibility associated with each sector. Based on statistical data published by the UPME (Energy and Mining Planning Unit), the authors assume that the exergy performance of the economic sectors evolves at rates that, at least, reflect the same trend observed in the energy performance of the various energy sectors throughout the timeframe considered. The analysis shows that the overall exergy efficiency is low (8.5% in 2016) although it also shows a steady increase during the timeframe. As a conclusion, a progressive change of the utilization of the Colombian energy resources, favouring the use of electricity and natural gas instead of firewood is observed. This trend results from the development of a population from a rural to urban structure.

3. Heat demand in buildings

Buildings account for a large share of the primary energy consumption. Many initiatives at both European, national and municipal levels have mandated and promoted the increase in energy efficiency in buildings. Monitoring is paramount to develop the correct policies. Urquizoa et al. [4] developed an alternative method for mapping and monitoring heat loss from a group of buildings using imagery from an airborne thermal remote sensing and a building-based energy use framework to reduce energy use. The use of high-resolution airborne sensors can be correlated with energy use to help interpret the imagery data and assess the influence of environment landscape, dwelling clustering in energy use.

This method was applied to a low residential density location in Newcastle, United Kingdom, where the local area characteristics play an important part in the energy efficiency. The microclimate is likely to have affected the results due to vegetation, which in urban areas plays a significant role in regulating the climate. Vegetation is an effective measure to create an “oasis effect’” and mitigate urban warming at micro levels.

Additionally, when vegetation is arranged throughout a city in the form of parks, the energy balance of the whole city can be modified by providing sources of moisture for evapotranspiration and more absorbed radiation can be dissipated in the form of latent heat rather than sensible heat. The results show that different buildings have similar energy usage. Thermal imagery can be used for identifying heat losses and that vegetation regulate land surface temperature over the built environment.

4. Advanced heating and cooling systems

District Heating and Cooling (DHC) networks represent a viable and efficient way to distribute energy for space heating and cooling in urban areas with high density demand. In the European Union, the Energy Efficiency Directive 2012/27/EU promotes these systems to increase the use of RES and to increase the efficiency, by introducing the definition of 'efficient DHC' based on more sustainable multi-energy systems which require an increase of the Primary Energy Saving (PES) and a reduction of the operational costs and greenhouse gases emissions.

Lazzeroni et al. [5] present the design stages of a case study of a polygeneration system supplying an existing DHC network in the North of Italy through an optimization tool. Different possible configurations of a highly complex multi-energy system with RES integration are proposed and studied by means of the optimization tool XEMS13. This is able to minimize the operational costs considering technical constraints, energy prices and the regulatory framework. The economic optimization presented in this paper is based on a Mixed Integer Linear Programming (MILP) formulation. Four scenarios are considered for analysis. They range from separate heat and cooling supply, cogeneration of heat and power (CHP) and various RES and thermal storage. Taking into consideration the energy utilization profiles, the authors show that by adjusting the set point of the solar collector the low enthalpy from the collectors and the CHP cooling system could be coupled with a heat pump to supply heat at a higher temperature to the district heating. This configuration results in a PES of 25.9% and an overall efficiency of 91.5%.

Industrial facilities including power plants are potential sources of cheap and low-carbon waste heat, which is often not utilized due to lack of techno-economically viable options. Distance between the source and the user and mismatches between demand and supply, in addition to costs are the main limiting factors. Innovative technologies and approaches may bring such low value sources to the end user. Bose et al. [6] proposed a novel Mobile Thermal Energy Storage (M-TES) systems employing latent heat as an alternative to district heating. In this concept, the waste heat is stored as latent heat in a Phase Change Material (PCM) container that is used to deliver heat to the end user. In the present study, a hotel resort is selected as a case study. Heat is available from an energy crop anaerobic digestion (biogas) CHP plant. The energy use is integrated with auxiliary existing thermal systems - electrical boilers. For the various scenarios analyzed (of the M-TES and energy utilization patterns) it was concluded that a payback period of 7 years could be achieved which yields a 96.7% reduction in CO_2 emissions.

5. Transportation systems

The transportation sector is critical to the transition of the energy utilization. For the development of more effective solutions it is fundamental the definition of reliable and accurate driving cycles (DC). This will in turn will provide the best technical solutions for electric/hybrid vehicles which include: battery sizing; powertrain specifications; strategies for efficiency and emissions reduction; energy logistics. Driving cycles - used for testing and development - are based on driving patterns that should match in characteristic parameters (CP): speed, acceleration, operation mode, dynamics, Speed Acceleration Probability Distribution.

For assessing the accuracy of a driving cycle to represent a driving pattern, stochastic (Micro-trips, Markov-chains) and deterministic (MWD-CP; Minimum weighted difference - characteristics parameters) methods can be used. Huertas et al. [7] established that a DC represents a driving pattern when the CPs of the driving cycle are similar to the CPs of the driving pattern. They evaluated the degree of representativeness as the relative difference between paired CPs. The authors find that for a typical route with a high variety of driving patterns, the MWD-CP method produced a DC that describes the driving pattern in that region with the highest level of representativeness. All of its CPs were similar to the CPs of the driving pattern with relative differences below 20% - except for idling time. The MWD-CP method is a deterministic, repeatable and reproducible method designed to construct DCs that reproduce real energy consumption. These important advantages over the other methods of constructing driving cycles are mitigated by its major drawback which is the need of weighting factors that vary with the region under consideration.

Electrification of vehicles is the major route for decarbonisation and emission reduction in the transport sector. The development of solutions such as hybrid, plugin hybrid electric vehicles, and electric vehicles depends on the vehicle segment and utilization. In order to properly design the energy system one has to account for physical, economic and environmental variables, also known as environomic design. Dimitrova and Maréchal [8] present an application of the environomic optimization methodology for optimal design and operation parameters of the vehicle energy system that deals not only with the energy consumption and economics, but also with the environmental impacts. A multi objective optimization with three objectives is used to define solutions for optimal efficiency, economic and environment, measured in terms of Global Warming Potential for a life span of 100 years.

The model assumes the New European Driving Cycle (NEDC) to model the energy flow of a Hybrid-Diesel vehicle. For energy storage, both batteries and capacitors are considered. The optimization methodology is based on a genetic algorithm and is applied for defining the optimal set of decision variables for powertrain design. The optimization solutions for the three objectives are presented in a Pareto front, which shows that GWP decreases with efficiency albeit at an increasing cost. The solutions in the lowest emissions zone show that the maximal powertrain efficiency on NEDC is limited on 45.2% and the minimal tank-to-wheel CO_2 emissions are 30 g CO_2/km. They have the maximal cost – 75,000 EUR.

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