European Journal of Operational Research 000 (2018) 1–19

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Combining local preferences with multi-criteria decision analysis and linear optimization to develop feasible energy concepts in small communities

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ARTICLE INFO

Article history:
Received 2 December 2016
Accepted 16 January 2018
Available online xxx

Keywords:
Community operational research
Sustainable energy
MILP
MCDA
Uncertainties

ABSTRACT

Decentralised community energy resources are often abundant in smaller, more rural communities. Such communities often lack the capacity to develop extensive energy concepts and thus to exploit these resources in a consistent way. This paper presents an integrated participatory approach to developing feasible energy concepts for small communities. The novelty lies in the combination of methods, the consideration of uncertainties, and the application to an exemplary municipality in Germany. Stakeholder workshops are combined with energy modelling and multi-criteria decision analysis (MCDA), and a high transferability is ensured with mainly public data. The workshop discussion revealed three values: economic sustainability, environmental sustainability, and local energy autonomy. A total of eight alternatives for the 2030 energy system are identified to achieve these values. We find that an alternative that seeks only maximization of economic sustainability should be rejected based on elicited preferences. Instead, several alternatives seeking a maximization of environmental sustainability with constraints on economic sustainability (i.e. total cost) and local energy autonomy consistently achieve the highest overall performance scores. A maximization of economic sustainability or local energy autonomy alone results in the lowest overall performance scores and should therefore not be pursued by the community. The intermediate alternatives demonstrate that an equivalent performance gain with respect to autonomy comes at higher costs than the same gain with respect to environmental sustainability. Similarities between the best performing alternatives in terms of technologies that can be installed by 2030 show that our methodology can generate concrete and robust recommendations on building-level measures for energy system design.

1. Introduction

Local communities have a key role to play in the transition towards more sustainable energy systems. Within municipalities, buildings account for about 40% and 36% of the total European end energy consumption and greenhouse gas (GHG) emissions, respectively (De Groote & Rapf, 2015). Whilst the energy-political framework, including overarching targets and policies, are set at national and regional levels, the implementation of measures towards this end occurs at the level of individuals and municipalities. Currently, there are numerous international examples of municipalities that voluntarily strive for sustainability targets in the absence of binding national or international commitments. A recent trend towards so-called community energy (Walker, 2008; Walker, Devine-Wright, Hunter, High, & Evans, 2010) in Europe has been particularly strong in Germany. Here, 46% of renewable energy capacity could be classified as community energy in 2012 (Klaus Novy Institut e.V. & trend:research, 2011), which is mainly owned by private individuals and farmers. In this domain, many communities attempt to increase the fraction of energy supplied by renewable sources and improve the energy efficiency of existing buildings and infrastructure. Some of these communities are involved in the Covenant of Mayors (Kona et al., 2015) and/or the Energy Efficiency Award[1], two voluntary European initiatives that

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[1] A European award aiming at recognizing and benchmarking municipalities' efforts to improve their energy efficiency. At the time of writing there are around 1400 municipalities participating, 310 in Germany: http://www.european-energy-award.de/eea-kommunen/.

https://doi.org/10.1016/j.ejor.2018.01.036
0377-2217/

recognize local action in this field. At one end of the scale are relatively small-scale projects in which members of the community establish a co-operative or similar financing structure in order to invest in one or several wind turbines – 718 such energy cooperatives have been founded since 2006 (DGRV, 2014). At the other end of the scale, larger projects involve communities declaring ambitious goals with respect to renewable generation, CO_2 emission reductions and/or energy autonomy[2], in some cases even buying the local electrical distribution network back from the local utility.

The problem addressed in this paper is on the one hand the lack of resources that smaller municipalities have for developing energy strategies, on the other hand the lack of decision support methods to assist them in doing so. Many communities are enthusiastic to undertake some grassroots action towards sustainable energy, but often lack the guidance to do so effectively. Against this background, we have developed an energy system model for community energy systems, which takes a central planner perspective, uses mostly open source data inputs and thus has a focus on transferability (Mainzer, McKenna, & Fichtner, 2015). Moreover, we use multi-criteria decision analysis (MCDA) in stakeholder workshops to provide guidance for and support the discussion and development of energy concepts with local communities. This contribution therefore combines these two areas by applying the community-level energy system model along with MCDA in the context of a case study to a community in the south west of Germany. The method is tailored to smaller municipalities, because these typically have fewer technical, administrative and economic resources (than larger ones) to devote to sustainability projects (Marinakis, Doukas, Xidonas, & Zopounidis, 2018; Polatidis & Haralambopoulos, 2004). The main novelties compared to existing contributions lie in the combination of an existing optimization model and MCDA framework to allow structured alternative formulation and the overarching participatory approach to the problem with key stakeholders, which explicitly considers uncertainties through a multi-dimensional sensitivity analysis and culminates in a natural language generation module (Wulf & Bertsch, 2017).

This contribution is therefore an example of mixing methods, including prescriptive and quantitative decision modeling, within the field of Community Operational Research (Community OR). In the combination of methods of soft and hard OR, it explicitly addresses the middle ground between the two (Johnson, 2012), and involves a meaningful engagement with a community, which has been proposed as a working definition for Community OR (Midgley, Johnson, & Chichirau, 2018). The focus is thereby on an underrepresented and underserved population (Johnson & Smilowitz, 2007), namely one that wishes to be actively involved in local energy initiatives, but lacks the resources and expertise to do so. Amongst three identified emerging trends of disaster planning, analytics and behavioural OR, this paper is mostly concerned with the second, i.e. “the design of policies, guidelines or practices based on the optimal or best possible values of decision variables assumed to be under control of the modeler” (Midgley et al., 2018, p.4). Two of the nine new frontiers identified by Midgley et al. (2018) are also especially relevant in the present case: urban planning and community development (alongside Feretti & Gandino, 2018, in this issue), and environmental issues. Despite this relevance, the analysis of energy systems has been a marginal area of Community OR, which this paper goes some way to address.

The paper is structured as follows. Section 2 reviews relevant literature on MCDA and energy modelling, with a particular focus on national and community-level approaches, as well as problem structuring and weighting/scaling in MCDA. Section 3 then presents the integrated participatory framework developed in this paper, before Section 4 applies this approach to the case study municipality. The structure of Sections 3 and 4 is intentionally similar (although not identical) and the process presented in Section 4 is roughly chronological in nature. Section 5 subsequently discusses key aspects of the method in general as well as the employed criteria. The paper closes with conclusions and recommendations in Section 6.

2. Related work on MCDA and energy modelling

This section reviews relevant literature on MCDA and energy modelling, hence providing the theoretical and empirical background for the study. The focus is on MCDA and sensitivity analyses (Section 2.1), national approaches and relevant criteria (2.2), and community-level approaches (2.3).

2.1. MCDA and sensitivity analysis

The complexity of real-world problems has increasingly led researchers to combine multiple methods in order to provide richer insights (Mingers, 2001). There is an extensive and growing literature on mixing methods (e.g. Mingers, 2001; Ormerod, 2001), but successful examples in the context of environmental decision and policy making are scarce (Myllyviita et al., 2014). Examples include the combination of decision support methods such as Multi-Criteria Decision Analysis (MCDA) with surveys, workshops and focus groups.

Multi-criteria decision analysis (MCDA) represents a formalized framework, which draws on a variety of methods to provide transparent and systematic support in complex decision situations (Stewart, 1992). The methods explicitly acknowledge subjectivity in decision making, provide a framework for sensitivity analysis, and offer support for building consensus in group decision making. In general, MCDA comprises both methods that seek to find an optimal solution amongst a theoretically infinite number of alternatives (e.g. with multi-objective mathematical programming methods) and methods that seek to sort a finite set of discrete alternatives under consideration of the decision makers' (DMs) subjective preferences (Duarte & Reis, 2006). We shall focus on the latter only in this paper and refer to these as MCDA methods throughout the rest of the paper. Multi-attribute value/utility theory (MAVT/MAUT) can be considered one group of methods within this category, using linear additive value functions or multiplicative nonlinear utility functions to identify and rank a set of discrete decision alternatives (see Keeney & Raiffa, 1976 for an overview). Subjectivity and uncertainty surrounding the alternatives' consequences make uncertainty and/or sensitivity analyses indispensible.

MCDA typically comprises four key phases. *First*, the core challenge in most MCDA applications is recognising, understanding and structuring the problem (Ferretti, 2016). This includes identifying the (key) stakeholders and understanding their perspectives in terms of their values and objectives (Belton & Stewart, 2003, Ch. 3). Engaging involved stakeholders in an unstructured way is quite straightforward, but producing usable constructs from such unstructured answers is methodologically challenging (Brugha, 2000a). The goal of structuring the problem is to break down values into measureable attributes to assess possible solutions. At the same time, feasible alternatives are identified alongside attributes which are employed to quantitatively analyse these alternatives. The set of attributes should be complete and exhaustive, and restricted to only those with no conceptual overlap.

There is an extensive and longstanding literature on problem structuring. More recently, these methods have been referred to as Problem Structuring Methods (PSMs) (Belton & Stewart, 2010), but Eden and Ackermann (2006) stress that they do much more

[2] Defined here as the fraction of annual local energy demand that is met by local (renewable) generation.

Please cite this article as: R. McKenna et al., Combining local preferences with multi-criteria decision analysis and linear optimization to develop feasible energy concepts in small communities, European Journal of Operational Research (2018), https://doi.org/10.1016/j.ejor.2018.01.036