Energy Policy 91 (2016) 174–188

Contents lists available at ScienceDirect

Energy Policy

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

Mountainous areas and decentralized energy planning: Insights from Greece

Nikolas M. Katsoulakos*, Dimitris C. Kaliampakos

National Technical University of Athens, 9 Heroon Polytechneiou Str., Zographos 15780, Greece

HIGHLIGHTS

- The influence of mountains' characteristics on energy planning was analyzed.
- Optimal energy solutions present differentiations with respect to altitude.
- Greater socioeconomic benefits by energy optimization in mountainous areas.
- Remoteness favors the development of decentralized energy systems.
- The study is based on data from Greece.

ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form
30 November 2015
Accepted 9 January 2016

Keywords:
Energy planning
Mountainous areas
Linear optimization
Socioeconomic cost
Energy poverty
Altitude

ABSTRACT

Mountainous areas have particular characteristics, whose influence on energy planning is explored in this paper, through a suitably tailored methodology applied to the case of Greece. The core element of the methodology is a linear optimization model with a "total cost" objective function, which includes financial, as well as external costs and benefits. Altitude proves to have decisive influence on energy optimization results, because it affects energy demand. The improvement of local energy systems provides greater socioeconomic benefits in mountainous settlements, due to the high shares of renewables and energy efficiency interventions in the optimal solutions. Energy poverty can be alleviated by redesigning local energy systems and the structure of the energy market. However, spatial and aesthetic restrictions, presented often in mountainous settlements, may affect the operational costs of energy systems, which is a crucial parameter for confronting energy poverty. Furthermore, the study indicates that it could be better to electrify remote areas, far from electricity grids, by decentralized systems than by grid expansion. The results of this study and the assumptions made about the way in which energy market should function, could be utilized for reconsidering energy policy measures, aiming at supporting sensitive societies to improve their development perspectives.

1. Introduction

Despite the significant local differentiations, mountainous areas have plentiful renewable energy potential, among other valuable natural resources and this is attributed to their geographical features, as well as to high-altitude climate (Funnell and Parish, 2001; Price, 2002; Katsoulakos, 2013). This fact was included in the 13th Chapter of Agenda 21, which is related to the protection and the sustainable development of mountains. In this Chapter of Agenda 21 it is mentioned that mountains are an important source of energy (United Nations, 1992). Nevertheless, this rich energy potential is not utilized in favor of local societies, as a rule (Euromontana, 2010). Moreover, they face serious problems in energy supply, mostly, because of the current, broadly applied energy policies that give priority to territories with high energy consumption, when expanding electricity grids (Coello, 2011; Johansson and Goldemberg, 2002). Therefore, mountainous areas end up exposed to energy/fuel poverty (Katsoulakos, 2011). This fact in combination with deficient access to basic commodities (according to the Food and Agriculture Organization of the United Nations, about 35% of the world's population is vulnerable to food insecurity) in these areas downgrade their development perspectives.

Sustainable development policies should have as a core component viable and environmentally friendly energy strategies. In cases of areas, which include fragile ecosystems and sensitive societies, like mountainous ones (UNEP-United Nations Environment

* Corresponding author.
E-mail addresses: katsoulakos@metal.ntua.gr (N.M. Katsoulakos), dkal@central.ntua.gr (D.C. Kaliampakos).

http://dx.doi.org/10.1016/j.enpol.2016.01.007

Programme, 2011), decentralized energy planning that takes into account the particular conditions of the surrounding environment could produce advantageous results for local societies. Various studies are related to energy applications and energy optimization in mountainous areas (e.g. Beni et al., 1994; Schweizer-Ries, 2001; Arnette and Zobel, 2011). However, the literature about the interactions between mountainous characteristics and the energy sector is rather poor (e.g. Foerster et al., 2011; Katsoulakos and Kaliampakos, 2014). This paper attempts to cover aspects of these interactions by studying the influence of mountain characteristics on energy planning, based on the case of Greece. Greece is a country with about 70% of its territory characterized as mountainous. A lot of small and medium – sized settlements are located at the mountain ranges of the country and therefore, Greece is appropriate as a case study (Nordregio, 2004).

The main features of mountainous space, which potentially have influence on energy planning, as well as a short description of their influence are listed below (Katsoulakos, 2013):

Geographical characteristics

1. **Altitude**: The basic feature of mountainous areas. It is the second most important parameter affecting climatic conditions after latitude (Funnell and Parish, 2001) and has an influence on all basic climatic characteristics, including temperature, solar radiation, humidity, precipitation etc. Temperature falls with respect to elevation and so, heating degree-days decrease, too. Hence, mountainous settlements present particularly increased thermal loads and higher total energy loads than lowland or coastal areas (Katsoulakos and Kaliampakos, 2014). Metsovo, a mountainous town in the Region of Epirus, in Greece, lying at an altitude of 1250 m has 2.6 times more heating degree days than the town of Kerkyra, lying by the sea at almost the same latitude. The particularly increased energy needs of Metsovo, combined with the ongoing crisis and the rise in diesel oil prices, has led to a two times higher share of biomass systems for heating than the country's average (Katsoulakos, 2013).
2. **Inclination**: It has been mentioned that flat land is the most valuable resource in highlands, which are characterized by particularly steep soils (Peattie, 1936). In Greece, municipalities need to have an average slope inclination between 16% and 20%, in order to be defined as mountainous ones. The steep slopes of mountainous areas reduce the available and suitable spaces for human activities and therefore, restrict the space for locating energy units and systems, especially those needing plenty of space, like photovoltaic parks or biomass combustion units.
3. **Remoteness**: It characterizes many mountainous settlements, due to the high relief and sets obstacles to the energy supply. Isolated areas are usually the last to be electrified, when energy companies expand the grids (UNDP, 2000). Moreover, the great distance from major industrial/commercial centers and the often inadequate road networks increase the costs of fuel in mountainous areas. For instance, in the regional unit of Evrytania one of the remotest mountainous regions in Greece, the fuel prices are about 6% higher than the country's average, according to the Greek Secretariat of Trade.

Socioeconomic characteristics

1. **Limited economic activities and low income**: Remoteness, lack of useful space and other parameters do not allow mountainous areas to develop strong and large-scale productive activities, as a rule. So, mountain populations, usually, have lower incomes than people in lowland and urban areas. In 2010, in Greece the mean annual household income was 24,224 € (ELSTAT – Hellenic Statistical Authority, 2012), whereas in one of the comparatively rich mountain municipalities (Karpenissi) it was 18,603 €, 25% lower than the average. Low incomes combined with high thermal loads and increased fuel costs make mountain societies particularly vulnerable to energy poverty. Therefore, confronting energy poverty should be a priority of sustainable energy planning in mountainous regions.
2. **Old building stock and vernacular architecture**: Energy poverty is further enhanced by the low energy efficiency of the often old building stock of mountainous settlements; in Greece, in the majority of mountain settlements more than 55% of the buildings are built before technologies and regulations regarding thermal insulation were applied (Katsoulakos, 2013). Finally, the need to protect the vernacular architectural identity also affects energy planning, since it sets restrictions to the application of modern energy technologies. For example, in the mountainous town of Metsovo, in the Region of Epirus, in which special legislation about the aesthetics of buildings is applied, solar thermal panels and photovoltaics are not allowed to be installed.

In the present paper, a systematic approach for quantifying the influence of these characteristics on energy optimization is presented. The basic concept of the analysis is the application of an optimization model to a hypothetical settlement and the study of the differentiation of the optimal solutions, with respect to the parameters of mountainous character. The hypothetical settlement was composed according to data and estimations that correspond to the situation in Greece. However, by adjusting the methodology developed to the characteristics of other countries/regions, it is relatively simple to extract the corresponding conclusions. By revealing differentiations in energy optimization which emanate from mountainous character, the analysis aims at highlighting the necessity for specialized energy planning in highlands and at reconsidering aspects of renewable energy systems development. The conclusions extracted correspond, mainly, to the Greek case.

The optimization model has been specifically formed, in order to support the aforementioned procedure. It is based on a variety of energy technologies, between them energy efficiency interventions, which constitute the decision variables. The inclusion of energy efficiency interventions as decision variables is an important feature of the optimization model and proves to be crucial for energy planning in mountainous areas, which have increased energy loads. Its objective function has monetary dimensions and includes both private costs (capital and operational costs) and external costs/benefits (environmental and employment externalities). The optimization model developed is flexible and can be easily transformed, in order to study the influence of mountain characteristics on the results.

The methodological framework for approaching the problem is presented in Section 2. Section 3 contains the results of the optimization and the basic findings related to the influence of mountain characteristics on energy planning. In Section 4 estimations about how the results of the study can affect energy policy are mentioned. Finally, in Section 5 the most important points are summarized and conclusions are extracted.

2. Methodology

The energy planning model is based on the method of linear optimization. The mathematical model contains a one-variable objective function which has cost dimensions, as already mentioned. In order to include the environmental and social dimension in the optimization model, the environmental and social criteria have been expressed at a monetary basis, by utilizing findings from research works based on the techniques and methods of environmental economics (e.g. damage function