The energy identity of mountainous areas: the example of Greece

Nikolas M. KATSOULAKOS[1*] http://orcid.org/0000-0002-0676-2175; e-mail: katsoulakos@metal.ntua.gr

Dimitris C. KALIAMPAKOS[2] http://orcid.org/0000-0001-5819-6075; e-mail: dkal@central.ntua.gr

** Corresponding author*

1 National Technical University of Athens, Metsovion Interdisciplinary Research Center, Agias Triados 200, 44200 Metsovo, Greece

2 National Technical University of Athens, School of Mining and Metallurgical Engineering, Herron Polytechneiou 9, 15780 Zographos, Greece

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Abstract: Mountainous areas have been long recognized as particularly important for the planet and sustainable mountain development is a global priority. In order to improve the socioeconomic development perspectives of mountain societies, efficient and well-targeted energy strategies should be formed. An important step towards this direction is adequate understanding of local conditions and specific features that affect energy sector. This procedure allows the inclusion of "locality" in energy planning and so, decentralized energy production is facilitated. The present study attempts to determine the particular energy identity of mountainous areas. Greece, which is the second most mountainous country in the EU, has been selected as a case study. Essential features of the mountainous space have been selected, namely altitude, inclination, remoteness, lack of productive activities, old buildings/ vernacular architecture, in order to explore their interrelation with the energy sector. Based on literature review and research findings the interaction between mountainous character and energy is outlined. Therefore, a framework of the characteristics of mountain energy identity is composed, which can provide support to the formation of specialized energy policy for mountainous areas. Some of the main findings of the present study include the significantly increased energy loads of mountainous areas, the abundance of renewable energy potential in high – altitude areas, the vulnerability of mountain societies to energy poverty and the difficulties in sitting energy projects in the restricted usable space of mountains. Since the literature regarding mountains and energy is rather poor the present paper aspires to be a step towards highlighting the importance of energy issues for mountain areas and societies. By determining the features of mountain energy identity energy planning in high – altitude areas and so, helping make energy planning more effective, such research works can be parts of sustainable development strategies for mountainous areas.

Keywords: Energy demand; Renewable energy potential; Energy poverty; Mountain energy policy; Mountain energy identity

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Introduction

Sustainable mountain development has been set as a global priority since 1992. After the historical Rio Earth Summit, a global plan of action was adopted, known as Agenda 21. The 13th

Chapter of Agenda 21 is entitled "Managing Fragile Ecosystems: Sustainable Mountain Development" and is dedicated to mountains. The Chapter begins with the statement that mountains "are an important source of water, energy and biological diversity" (UNEP 2011). Indeed, mountainous areas are characterized by plentiful energy potential because of their geography and climate, as a rule (Funnell and Parish 2001; Price 2002; Katsoulakos 2013). Nevertheless, renewable energy potential is just a part - despite its importance - of the issues related to energy and energy policy. In order to better understand the energy identity of mountainous areas, the differentiation in energy needs, the necessary energy costs for covering them, the characteristics of the building stock and other aspects need to be investigated, too.

The literature related to energy and mountains is rather poor (e.g. Foerster et al. 2011; Katsoulakos and Kaliampakos 2014; Katsoulakos and Kaliampakos 2016; Papada and Kaliampakos 2016a). At the same time, a series of problems related to energy issues in mountainous areas has been recognized. The European Association of Mountainous Areas – Euromontana – in an energy related report comments that the renewable energy resources of mountains are usually not utilized in favor of local societies (Euromontana 2010). Coello (2011) notes that in developing countries, the majority of mountain population does not have access to electricity and comments that a decentralized approach to energy planning may have positive impacts on solving this issue. In the developed world, an increasing number of people is facing problems with access to sufficient and affordable energy, a problem defined as energy poverty. Papada and Kaliampakos (2016b, 2017) have proved that mountainous communities are particularly vulnerable to this situation, mainly because of the cold climate and the generally low incomes of mountain people. The studies of Katsoulakos and Kaliampakos (2014) and Papada and Kaliampakos (2016b) show that thermal energy needs increase significantly with respect to altitude and so, mountain residences demand high energy quantities and are burdened with great energy costs.

Energy is closely related to quality of life and socioeconomic development. The construction and operation of energy units, as well as the use of various fuels have environmental impacts. So, an integrated mountain policy, aiming at the protection of mountain environment and the development of local societies, must include energy issues as a core part. Taking into account the abovementioned facts, it is obvious that mountains present particular characteristics, as far as the energy sector is concerned. Hence, in order to form a specialized, effective energy policy for mountain regions, it is important to better understand these particularities. The necessity of understanding the special energy identity of mountain areas is supported by the research of Katsoulakos and Kaliampakos (2016), which has shown that mountain characteristics have significant influence on energy planning. Moreover, the need for wider use of renewable energy leads to extensive research and investments in smart/ micro grids. For instance, in Europe, according to Gangale et al. (2017), there are 308 ongoing projects related to microgrids, with a total budget of 2.15 billion euros, while 642 projects, with a total budget of 2.82 billion euros have already been completed. The development of microgrids is closely bound to decentralized energy production and planning. Therefore, understanding local conditions and energy profiles is important for supporting decentralized energy optimization.

Greece is worldwide famous for its islands and its coastline, in general. However, the country's mainland is mountainous. Greece is the second most mountainous country in the EU (Nordregio 2004). The mountain territories have played an essential role in the country's history between the 15th and the first half of the 20th century. After the Second World War, the majority of mountain populations migrated to urban centers (both within the country and abroad). This led to the marginalization of mountainous Greece and its exclusion from the main development policies (Matsouka & Adamakopoulos 2008; Lafazani 2010). There is still no integrated policy for the mountainous space in Greece, apart from fragmentary, short-term measures. The economic crisis that the Greek society has intensely faced, has affected mountain Greece, too. One of the most important impacts of the crisis in mountain territories is the intensification of energy poverty, whose alleviation is a prerequisite for improving the quality in these areas (Kaliampakos 2013). As a part of the austerity policies applied in Greece after 2009, the price of fuels has risen significantly. The increase in taxes and levies is the main factor that led to this increase, as shown in Table 1; taxes and levies in 2015 were 2.2 times higher than in 2008. This severe increase in fuel prices has particularly affected mountainous areas, because of their high thermal energy demand. Current policies have been proved inadequate for confronting energy poverty and they do not contain any specific measures for mountain settlements (Katsoulakos 2013, 2014). This lack of policies in the energy sector reflects the general absence of mountain policy in a highly mountainous country.

Table 1 Percentiles of components of heating oil prices in Greece for the years 2008 - 2015

Year	Taxes and levies	Wholesale costs & supplier costs and margins
2008	20.5%	79.5%
2009	20.8%	79.2%
2010	21.6%	78.4%
2011	25.6%	74.4%
2012	35.2%	64.8%
2013	45.2%	54.8%
2014	44.6%	55.4%
2015	45.5%	54.5%

In order to find effective solutions to problems like energy poverty in mountainous Greece a holistic approach to the energy identity of mountainous Greece is necessary. This paper provides an overview of essential aspects of the energy sector in mountainous Greece and their impacts on energy planning and policy; it advances the relevant findings that were firstly introduced in the doctoral thesis of the corresponding author (Katsoulakos 2013). The interrelations between some basic physical and socioeconomic characteristics of mountainous areas and the energy sector are analyzed. In this way, a basic guide to the energy identity of mountainous Greece is produced, based on well documented facts. This guide is a first step in the direction of developing specialized energy policy for mountainous areas.

1. Materials and Methods

The basic working hypothesis of the present paper was that mountainous areas have a particular energy identity, because of their special characteristics. In order to verify the validity of this hypothesis, the general methodological framework is based on the following rationale: A set of major characteristics of mountainous space is selected, whose environmental, socioeconomic and technological impacts are highlighted. The characteristics of mountains, which potentially have influence on the energy sector and were chosen to be studied, are:

Geographical characteristics

- Altitude
- Inclination
- Remoteness

Socioeconomic characteristics

- Old building stock
- Lack of productive activities

Then, the implications and interconnections with the energy sector are investigated. Greece is a country with particularly mountainous terrain and so, it has been selected as a case study. The determination of the interrelations between the features of mountainous areas and the energy sector has been based on literature review and previous work of the authors. Moreover, the work is supported by data collection and analysis, as well as specific examples. The necessary data for supporting the present study have been retrieved by: the Greek Statistical Authority (ELSTAT), the Greek Regulatory Authority for Energy (RAE), the Center for Renewable Energy Sources (CRES), the National Observatory of Athens (NOA) and research findings from relevant studies. Because of the importance of altitude, particular attention has been attributed to its role and interrelation with energy demand. The analysis included as a core part the relation between altitude and degree – days, in order to proceed with the quantification of energy needs with respect to altitude.

The analysis made in the present paper verified the working hypothesis, since the interrelations between the mountain characteristics and the energy sector proved to be important. The findings are related to four main aspects, namely energy needs, energy potential, socioeconomic impacts of energy demand/ consumption, restrictions in developing energy projects. The main results are summarized in a Graph, in order to gain a supervisory view of the subject. Based on the conclusions of the study, proposals regarding energy policy for mountainous territories are made. The methodological steps followed in the paper are presented in Figure 1.

2 Results and Discussion

2.1 Altitude and energy

Altitude is, apparently, the most distinctive characteristic of mountain geography. In our planet, 48% of the land area lies at altitudes over 500 m and 11% at altitudes over 2000 m (Parish 2002). The harsh conditions that prevail at high altitudinal zones lead to exponential reduction of population with respect to altitude. It is estimated that about 12% of the world's population lives in mountainous areas. Altitude is the most decisive factor for forming other characteristics of mountain areas, especially climate. Mountain climate is, in general, characterized by cold winters and short summers and this affects the energy needs of mountain settlements. Moreover, altitude is associated with renewable energy potential. The influence of altitude on climatic conditions has been pointed out by Peattie (1936), whose work is considered as one of the basic essays related to mountain areas. Peattie claims that the differentiations caused by altitude in climatic conditions are of decisive importance regarding life and economic activities in mountainous areas.

2.1.1 Energy demand

It is common sense that in high-altitude settlements the climate is colder and the winters are harsher. Besides, according to Oliver (2004), the evolution of the Köppen classification of climate types includes 6 climate types, among them the H type, which is characterized as "high altitude climate independently of latitude". Usually the climate of areas with an altitude over 1500 m is categorized as type H climate. However, it is important to investigate more specifically the differentiations of mountain climate, especially with regard to energy needs. The studies of Katsoulakos (2013), Katsoulakos & Kaliampakos (2014) and Papada & Kaliampakos (2016b) have focused on this matter and proved the great increase in thermal energy needs with respect to altitude. These studies have been based on heating degree days (HDD) and their increase with respect to altitude. HDD are a measure of how much and how long the outside temperature remains below a certain level. They are proportional to the thermal energy needs of buildings, according to the following mathematical expression:

$$E_{th} = H_{tot} \cdot HDD \cdot \frac{24}{1000}\ [kWh] \qquad (1)$$

E_{th}: Thermal energy demand of the building under study

H_{tot}: The total heat transfer coefficient of the building, including heat transfer due to conduction and ventilation

Regarding the calculation of HDDs and CDDs, since it is aimed to gain a general view of their differentiation with respect to altitude, the model suggested by Erbs et al. (1983), has been used. This method for calculating degree-days is based on monthly temperatures and so, it can be easily applied. It gives reliable results, especially in cases such as the one studied in the present paper. More specifically, firstly, the standard deviation of the mean monthly temperature, in relation with the mean annual temperature is calculated through the following equation:

$$\sigma_{yR} = \left[1/12 \cdot SUM\left(T_m - T_{yR}\right)^2\right]^{0.5} \qquad (2)$$

T_m: Average monthly temperature

T_{yR}: Mean annual temperature

Then, the standard deviation of the mean daily temperature of each month is calculated as:

$$\sigma_m = 1.45 - 0.029 \cdot T_m + 0.0664 \cdot \sigma_{yR} \qquad (3)$$

The average daily fluctuation of a month's temperature (h) is defined as:

For the case of heating

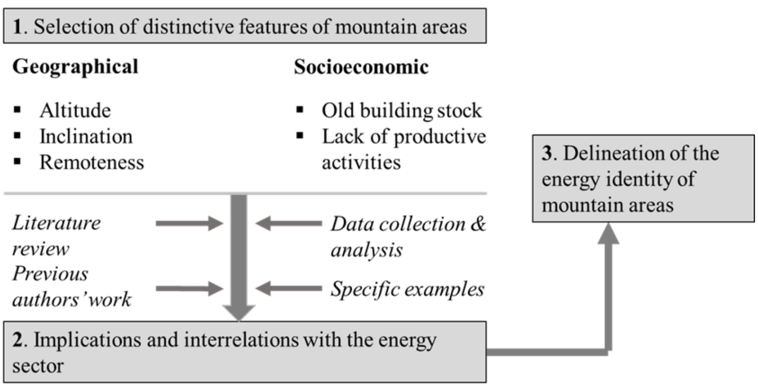

Figure 1 Synopsis of the methodology followed for delineating the energy identity of mountainous areas.

$$h = (T_b - T_m)/\sigma_m \cdot (N_m)^{0.5} \quad (4)$$

For the case of cooling

$$h = (T_m - T_b)/\sigma_m \cdot (N_m)^{0.5} \quad (5)$$

N_m: the number of the month's days. Finally, the degree-days are estimated, through the following mathematical expression

$$DD = \sigma_m \cdot N_m \cdot 1.5 \cdot \left\{\frac{h}{2} + \ln\left[\left(exp(-a \cdot h) + exp(a \cdot h)\right)/2 \cdot a\right]\right\} \quad (6)$$

α: A parameter equal to 1.698. In Greece, it is proved that altitude is the most crucial factor affecting HDD. The influence of altitude on regression models predicting HDD is 3.5 higher than the influence of latitude (Katsoulakos 2013; Katsoulakos & Kaliampakos 2014). A typical example of the altitude's influence on HDDs in Greece is the great differentiation of HDDs among the towns of Metsovo, Ioannina and Kerkyra (Corfu), whose HDDs are 3112 ^oC*days, 2030 ^oC*days and 1168 ^oC*days, respectively. These towns are located at about the same latitude, but they differ in altitude. Metsovo lies at an altitude of 1150 m, Ioannina at 483 m and Kerkyra at sea-level (Katsoulakos & Kaliampakos 2010).

The adjusted coefficient of determination (R^2) of a linear regression model for predicting HDD based only on the variable of altitude is 0.857, which is a rather high value. The findings are similar for the cases of Austria, Switzerland and Northern Italy (Papada & Kaliampakos 2016b). In these cases the latitudinal range is smaller than in Greece and so, the values of R^2 of single variable regression models predicting HDDs are higher; 0.951 in Austria, 0.955 in Switzerland and 0.933 in Northern Italy. So, conclusions regarding energy demand and consumption can be drawn by such estimations. HDDs increase with respect to altitude and this has direct impact on buildings' energy needs. A residence in Greece (with thermotechnical characteristics that respond to the minimum standards of the Greek Regulation for Energy Performance of Buildings) at an altitude of 1000 m has 2.7 times greater thermal energy demand and consumption than the same type of residence lying at sea level (Katsoulakos 2013).

On the other hand, the low temperatures of high – altitude areas result in reduced cooling loads during the summer. The parameter of altitude proves to be the most important factor affecting CDDs, as in the case of HDDs. Regarding CDDs, the linear one – variable (altitude) regression models present lower coefficients of determination than in the case of HDDs. However, the values of the adjusted R^2 of exponential regression models for Greece, Austria, Switzerland and Northern Italy are higher than 0.9. In the case of Greece, residences above 1000 m have very low cooling energy demand. Meteorological data from Austria, Switzerland and Northern Italy show that above 2000 m CDDs are practically zero (Katsoulakos & Kaliampakos 2014; Papada & Kaliampakos 2016b).

The great increase in thermal energy demand leads to high energy expenses in mountainous areas. In the case of Greece it is estimated that a household (assuming that it has good thermal insulation and uses diesel oil for heating and electricity for cooling) at the altitude of 1,000 m, needs to spend 72% more money for covering energy needs, compared to a house at sea level. These calculations include heating and cooling energy demand, as well as electricity consumption for other uses. The environmental footprint of energy consumption proves to be an ascending function of altitude. The CO_2 emissions of the energy consumption of a residence at 1,000 m are 27% higher than the corresponding emissions of the energy consumption of the same residence at sea level (Katsoulakos 2013, 2014).

The great differentiation of energy needs with respect to altitude affects significantly decentralized energy planning. This was firstly introduced by Katsoulakos (2013) and further developed by Katsoulakos & Kaliampakos (2016). In these studies, it was assumed that we need to optimize the energy mix for a hypothetical settlement, in order to cover its electrical and thermal energy needs. The optimization procedure was repeated for a range of altitudes, in order to take into account the differentiation of energy needs with respect to altitude. Indicatively, with respect to altitude the shares of energy saving interventions and biomass systems in the optimal energy mixes increase. At an altitude of 1,000 m the energy saving interventions' share in the optimum thermal energy mix is 2.1 times greater than at sea – level. This highlights the necessity of reducing energy demand, which is particularly increased in high – altitude areas.

2.1.2 Renewable energy potential

As already mentioned, mountains have been long recognized as sources of energy. Mountain climate and topography create favorable conditions for renewable energy potential. This is further analyzed in the following sections.

2.1.2.1 Solar energy

Starting from solar radiation, it is an ascending function of altitude. Due to the constant move of air masses in mountain slopes and other factors, the humidity is lower than in plain areas. The relative humidity at an altitude of 2000 m can be even 50% lower than at sea – level. So, the percentage of scattered solar radiation is reduced in mountainous areas, since the concentration of water molecules that can change the direction of photons is low (Aglietti et al. 2009). According to Barry and Van Wie (1974), in the Austrian Alps, the solar radiation increases by 21% in June and by 33% in December between two areas with an altitudinal difference of 2800 m. Other relevant research findings propose that the incident solar radiation grows by 7% – 10% per 1000 m of increase in altitude (Funnell & Parish 2001).

Apart from the increased solar radiation in mountainous areas, there is one more positive factor related to solar energy. When calculating the peak power of a photovoltaic system, a loss factor is used which has to do with the operation of the photovoltaic in temperatures different than the standard temperature, under which the photovoltaic is tested. This factor is given by the following equation (Perdios 2007):

$$\sigma_\theta = 1 - [(t_a + 30) - 25] \cdot 0.004 \qquad (7)$$

where t_a, the average air temperature of the month for which the system is designed

The peak power of a photovoltaic system is calculated by the following mathematical expression:

$$P_p = \frac{E_k \cdot 1kW/m^2}{E_{HA} \cdot \sigma_\theta \cdot \sigma_\rho \cdot \sigma_\eta} \qquad (8)$$

E_k: the electrical load to be covered by the system in kWh/day

E_{HA}: the mean daily incident solar radiation in kWh/m² • day

σ_θ: the loss factor due to temperature

σ_ρ: the loss factor due to photovoltaics' surface glare

σ_η: the loss factor due to electrical losses

Supposing that between two areas (area A and area B) all factors remain the same, apart from temperature and incident solar radiation, the ratio between the peak power of two photovoltaic arrays, will be:

$$\frac{P_{p,A}}{P_{p,B}} = \frac{\sigma_{\theta,B} \cdot E_{HA,B}}{\sigma_{\theta,A} \cdot E_{HA,A}} \qquad (9)$$

Let's use two areas in Greece, as an example; the town of Sparta (altitude 202 m) and the tourist shelter in the nearby mount Taygetos (1300 m). In July, the average temperature in Sparta is 30.1°C and in the shelter 20.8°C. Following what Funnell and Parish (2001) mention about the solar radiation difference between areas with altitudinal difference, it is assumed that in the area of the shelter the radiation is 8% higher. So, by applying the aforementioned equations, it is extracted that in the area of the mountain shelter, the peak power of a photovoltaic system could be 11% lower than in Sparta (dimensioned for the conditions of July).

Taking the abovementioned into account, the utilization of solar energy in mountainous areas can be particularly efficient. Not only photovoltaics, but also thermal solar systems can be applied in mountainous areas, despite some current, misguided opinions, which claim that the use of solar systems in cold climatic conditions should be avoided. The work of Beni et al. (1994), which describes a solar system mounted in a mountain shelter in the Alps at an altitude of 4550 m, shows that solar thermal systems could be a very good solution for providing heat, even in extreme conditions. More than two decades after the project described by Beni et al., the technological improvements of solar thermal systems have made their use in mountainous, cold areas easier and more efficient.

2.1.2.2 Wind energy

Generally, the wind velocity increases with respect to altitude. The wind masses, when coming up against barriers, like mountains, rise and accelerate. Another important factor that leads to wind speed increase is the decrease of the effect of friction between the Earth's surface and the movement of air in the free atmosphere with respect to altitude (Greenland 2005). The highest wind speed on earth (and not related to cyclones, hurricanes etc.) has been recorded in the top of

Mount Washington in the USA. "Valley winds" are another interesting meteorological phenomenon observed in mountainous areas, especially in valleys between mountain masses, illustrated in Figure 2. During the day, the ground is heated by the sun. The air masses above the ground are also heated and so, wind streams go up the mountain slopes. During the night the movement is reversed (Barry 2002). Valley winds cause constant move of air masses along mountain slopes. The increased wind speeds in ridgelines and the valley winds create favorable conditions regarding wind energy potential in mountainous areas, as a rule.

The Greek mountainous areas are a typical example, as regards plentiful wind energy potential. The Specific Spatial Planning Framework (SSPF 2008) for Renewable Energy Sources of Greece determines areas, where wind energy projects should be installed as a matter of priority. The determination of these areas – defined as wind energy priority areas (WEPA) – is based on wind velocity measurements across the country. As shown in Figure 3, the vast majority of WEPA, at a percentage of 80%, are mountainous and semi-mountainous.

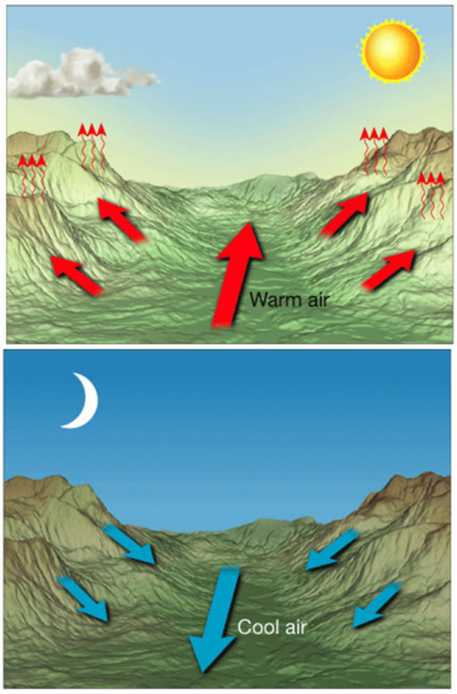

Figure 2 The mechanism of wind masses' movement in valleys between mountain masses (Military Strategy 2017).

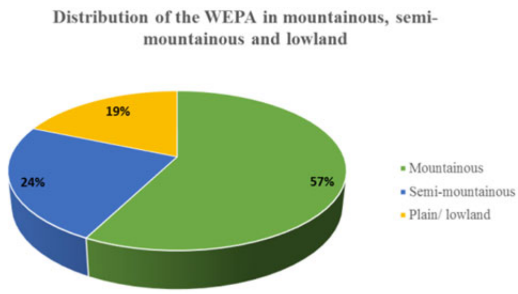

Figure 3 Distribution of Greece's Wind Energy Priority Areas (WEPA) in mountainous, semi-mountainous and lowland areas (SSPF 2008).

2.1.2.3 Hydroelectric energy

Hydroelectric energy is affected both by altitude and inclination. As regards altitude, a general pattern related to precipitation with respect to it has been proposed by Lauscher. There is a decrease of precipitation with elevation in equatorial latitudes, which is also observed, to a lesser degree, in polar areas. In midlatitudes there is a general increase of precipitation with respect to altitude (Barry 2002; Funnell & Parish 2001). The presence of mountain masses, itself, is a factor that affects precipitation and the mechanism of orographic precipitation is a phenomenon with major importance. According to Greenland (2005), the orographic precipitation can be shortly described as follows: "When air is forced to higher altitudes in its passage over a mountain, the air is cooled, and condensation of water vapor often gives rise to precipitation formation on the windward side." Snowfall is also increased in mountainous areas compared to areas with lower altitudes.

Taking the abovementioned into account, there are many cases of mountainous areas with abundance of water because of increased participation. The mountains of Greece are characterized by significantly higher rainfall than lowland areas. Orographic precipitation is also central part of the country's climatology. The mountainous range of Pindos that crosses the country from the North to the South has direct influence on rainfall. The windward western part of Pindos has much higher precipitation than the eastern part. Two typical examples illustrate the influence of altitude and mountain masses on precipitation in Greece: In the capital of Greece, Athens, the mean annual rainfall is 414 mm, whereas in the nearby mount of Parnitha - just 40 km from the center of Athens - at an altitude of

1000 m, the average annual rainfall is 822 mm. The mean annual rainfall in the town of Arta, at the windward side of Pindos, is 1084 mm, whereas in the town of Larisa lying at about the same latitude and altitude in the other side of Pindos, the annual rainfall is just 423 mm (Katsoulakos 2013).

The great number of water streams in the Greek mountains led to the utilization of water resources from the 17th century, through the use of watermills, hydraulic saws etc. Such systems were essential for the development of traditional societies (Economou – Botsiou 1998). During the 19th century, many mountainous villages and towns used hydraulic energy for developing processing activities, like leather tanning.

The mathematical expression of the theoretical power of a hydroelectric energy unit is the following:

$$N = \rho \cdot g \cdot Q \cdot H \tag{10}$$

ρ: the density of the water
g: the acceleration due to gravity
Q: the volumetric flow rate of the water stream
H: the hydraulic head

The two crucial factors regarding hydropower are flow rate and hydraulic heat. Flow rate depends is related to precipitation and so, it benefits from high – altitude climate. Hydraulic head is related to mountain topography and, particularly, inclination. Steep mountain slopes create good conditions for high hydraulic head. In the traditional applications, since the flow rate is given and dependent on the water stream, the presence of high hydraulic head is necessary. In modern, hydroelectric applications, through the construction of dams both the flow rate and the hydraulic head can be regulated. However, in the case of small hydroelectric plants, the flow rate again depends mostly on the water stream. So, the parameter of hydraulic heat becomes essential for increasing the power and the efficiency of the unit (Papantonis 2008). And this makes mountainous areas ideal for the development of small hydroelectric plants, since there is abundance of water resources and the steepness of slopes facilitates the increase in hydraulic head. About 80% of the small hydroelectric plants that are operating in Greece are located in mountainous areas. According to the Greek Regulatory Authority for Energy, among the 65 new small hydroelectric plants that have an operation license, just seven are located in non-mountainous areas (RAE 2015).

2.1.2.4 Biomass energy

The biomass which can be utilized for energy production can be divided into two main categories with respect to its origin:

- Products and residues of forest exploitation
- Organic residues from agricultural and livestock breeding activities

Unlike the aforementioned categories of renewable energy sources the estimations about biomass potential in mountainous areas cannot be easily generalized. Apart from climatic and other environmental parameters, the availability of biomass for energy utilization depends strongly on human activities. In the developing world many people, especially in rural and mountainous areas, depend on biomass for covering basic energy needs, like heating and cooking. In the wider area of the Himalayas, it is estimated that biomass covers over 70% of the residential energy needs (Khuman et al. 2011). The irrational use of resources, like firewood, is a major environmental risk for mountainous areas, highlighted more than 30 years ago by Shresta (1981). At the same time, deforestation makes collecting energy sources even more arduous for poor, local populations.

Focusing on Greece, mountainous areas are, generally characterized by rich forest biomass potential and restricted organic residues potential. More analytically, in Greece about half of the forested areas are located in mountains. Almost the total of the productive forests of the country is found in mountainous areas. Two main factors favor vegetation growth and lead to the existence of rich biomass potential in the Greek mountainous space; the increased precipitation and the low density and intensity of human activities. So, it can be said that altitude and remoteness, as features of mountainous areas, affect biomass potential in mountainous Greece. An indicative example is the one of Mount Taygetos in Peloponnese. The eastern part of the mountain between 700 and 1600 m is nowadays covered by dense coniferous forests. Until the beginning of the 20th century this zone was dominated by crops, mainly tree-based cultivation (Matsouka 2000). In many mountainous municipal districts all over the country forest cover is very high and this is

Table 2 Forest cover in mountainous municipal districts all over Greece (Katsoulakos 2013)

Municipal District	Total Area (km²)	Forest Area (km²)	Forest cover (%)
Athamania	306.7	234.0	76
Eastern Zagori	269.6	231.2	86
Eastern Olympus	153.0	100.0	65
Apodotia	256.2	201.7	79
Dimitsana	111.3	79.7	72
Zagora	96.3	75.7	79
Kalavryta	530.1	295.2	56
Karpenissi	250.6	201.6	80
Lidoriki	409.8	250.4	61
Metsovo	178.2	107.3	60
Oinous	302.1	228.4	76
Paranesti	789.3	719.2	91
Foloi	174.9	103.2	59

depicted in Table 2.

The case of Metsovo, mentioned in Table 2, illustrates the importance of forest biomass for covering energy needs. This small mountainous town in the Region of Epirus, with about 3000 inhabitants, has very high energy demand, because of its cold climate. The HDDs in Metsovo are 3112 °C*days, as already mentioned. It is estimated that the annual energy consumption of the settlement for heating exceeds 20.5 MWh and the thermal power demand exceeds 4.8 MW in January. The woody biomass produced annually in the area of Metsovo is about 15,800 tonnes (t). Less than the half of this quantity of biomass is enough to provide heat for about 70% of the households in Metsovo, according to the work of Katsoulakos et al. (2015). In the Region of Epirus, which is the most mountainous Region of Greece, it is estimated that about 65% of its thermal energy needs (this corresponds to 220,000 inhabitants) can be covered by forest biomass (Eurotec & CRES 2011). It should be mentioned that biomass is particularly important for mountainous areas, since it can primarily produce thermal energy – which is the main and greatest energy load in high – altitude settlements - by combustion. So, the rich biomass potential of Greek and other mountain areas, favored by altitude and remoteness is a valuable resource for local populations.

On the other hand, the biomass energy that can be retrieved from agricultural and livestock breeding residues is rather poor in the Greek mountainous areas. This happens because of reduction of the population and productive activities in these areas.

2.1.2.5 Problems regarding RES in mountainous areas

Despite the high renewable energy potential of mountainous areas, obstacles could be set to the development of RES projects in mountainous areas. As far as wind energy projects are concerned, the lack of high voltage networks in remote mountain territories affects negatively the exploitation of wind energy. Moreover, at high altitudes (over 2000 m), very high wind velocities, as well as low temperatures may cause destructive phenomena to wind generators (EEA 2009). The environmental impacts of wind farms, especially the issue of visual nuisance (Misthos et al. 2017) should not be neglected. Sitting wind farms in the sensitive mountainous environment should follow strict criteria. Regarding solar energy projects, the lack of suitable space for sitting them is the main problem in mountain areas. Moreover, solar energy units need to be installed at areas/slopes suitably oriented. This reduces even more the available areas for installing solar energy units in mountainous areas. It should also be noted that the increased solar radiation in mountainous areas led to some rather extreme plans. More specifically, it was proposed to install large photovoltaic arrays in ridgelines across the Himalayas, in order to utilize the plentiful solar energy potential and provide “green” electricity to densely populated areas of India and China lying at the foothills. Fortunately, these ideas were abandoned (Katsoulakos 2013). The remoteness of mountainous areas can set obstacles to the development of hydroelectric plants. The absence of high voltage networks in remote areas may cause problems to the utilization of hydropower potential. Moreover, even hydroelectric plants of small scale can cause major interventions both in the landscape and in the ecological balance of water bodies. In Greece, in the region of Epirus, many suitable spots for small hydroelectric plants are located in protected areas and national parks and this has caused social conflicts (CRES & Eurotec 2011).

2.2 Inclination and energy

Inclination is another major feature of mountain topography. Together with altitude it is used in many cases, in order to define whether an area can be categorized as mountainous (Basiouka 2011). The steep slopes of mountains reduce the available space for human activities and for building utilities. Peattie (1936) aptly states that the most valuable good in mountainous space is the presence of flat areas, since they facilitate agriculture. Since flat areas are crucial for agriculture and other activities, many mountain settlements are built in steep slopes, in order to ensure the maximum possible area for cultivation. In Table 3, some examples of mountain settlements of Greece are listed, which are built in areas with great altitudinal differences. The altitudinal differences in some cases exceed 400 m, within the same settlement. Moreover, great values of inclination can facilitate landslides in synergy with geological conditions (Koumantakis 2011). Landslide phenomena reduce even more the available space for human activities.

The influence of restricted space in the energy sector is related to the difficulty in siting energy projects, especially those which need plenty of space, like photovoltaic arrays. It is mentioned that siting photovoltaic in areas with inclination over 35% should be avoided (Eurotec & CRES 2011). The mountainous municipalities of Greece have average inclination over 35%, in order to be characterized as mountainous ones (Basiouka 2011). This is well illustrated in Figure 4, where the slope inclination of a Municipal district in the Region of Epirus has been captured on a map. In addition, as already noted, in many mountainous municipalities the forest coverage exceeds even 70%. Since it is not allowed to place energy units in forest areas, the available space becomes even less. Furthermore, land use conflicts may arise between plain areas suitable for agriculture and the siting of energy units. Finally, vulnerability to landslides can cause problems to energy projects.

On the other hand, inclination has a positive impact on energy sector, since it favors the development of small hydroelectric plants. This has already been noted in Section 2.1. Indicatively, let's suppose hydroelectric potential is available in an area with slope inclination 35% and in another area with slope inclination 10%. If in both areas the water flow is the same, as well as the length of the water supply pipeline, then the theoretical power in the area with the high inclination will be 3.3 times greater than in the area with the low inclination. Moreover, in cases with high hydraulic head - that can be created when the inclination is high - it is estimated that the installation costs of small hydroelectric plants may be up to 15% smaller than in cases, where the available hydraulic head is low (Papantonis 2008; Tsalemis et al. 2012). Hence, inclination favors hydroelectric production.

2.3 Remoteness and energy

The mountain terrain and topography result in the geographical isolation of mountainous areas. Mountain masses function as barriers and limits to the transition from and to them. Mountain towns and villages are located, usually, at great distances from urban and industrial centers, as well as main energy centers, like thermal power stations and oil refineries. Hence, as a rule, mountain populations have to travel great distances and spend much time, in order to reach major centers. In the case of Greece and particularly in the Region of Epirus, in which 66% of the settlements are mountainous, the inhabitants of mountainous areas need to spend much more time for traveling to the administrative centers. This is illustrated in Figure 5. The average time that the inhabitants of mountainous areas need to spend on travelling from their towns and villages to the administrative centers of their regional units is 2.3 times greater than the corresponding time of the inhabitants of plain areas. There is statistically significant correlation, at a confidence level of 99%, between travel-time and the categorization of the settlements as plain,

Table 3 Altitudinal range and inclination in mountainous settlements all over Greece

Settlement	Highest point (altitude in m)	Lowest point (altitude in m)	Horizontal distance (m)	Inclination (%)
Arachova	1,015	874	600	23.5
Karpenissi	1,080	836	1600	15.2
Langadia	1,085	875	900	23.3
Lampia	985	763	1000	22.2
Makrinitsa	760	320	1300	33.8
Metsovo	1,250	1003	1000	24.7
Syrrako	1,240	1070	420	40.4

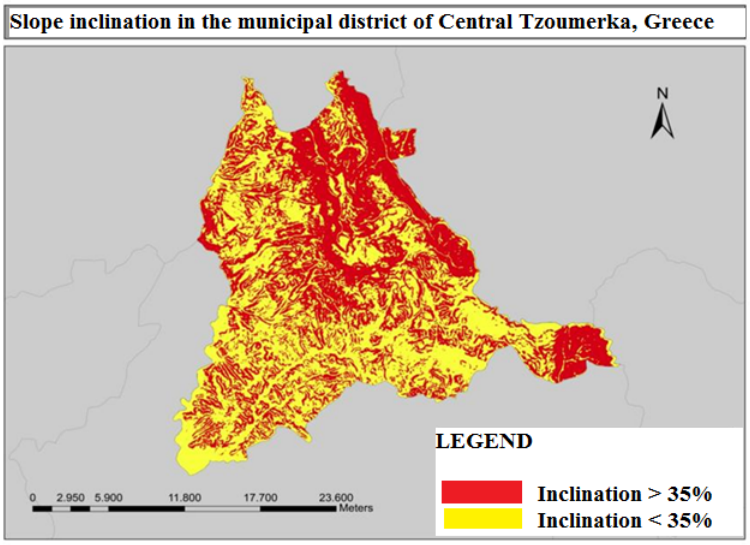

Figure 4 Slope inclination in the mountainous Municipal district of Central Tzoumerka, in the Region of Epirus, Greece (Coordinates X: 249221.57, Y=4370131.36 – EGSA 87).

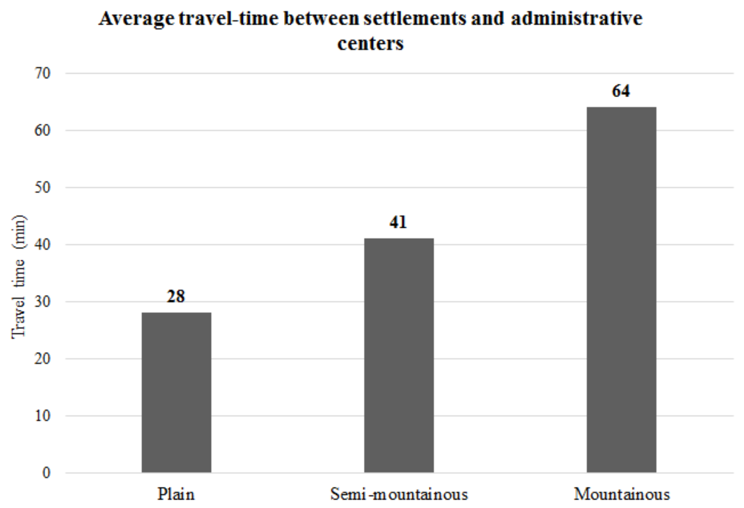

Figure 5 Average time for travelling from the seats of the R.U. to the lowland, semi-mountainous and mountainous settlements in the Region of Epirus (Mavriki & Kaliampakos 2016).

semi-mountainous and mountainous (Mavriki & Kaliampakos 2016).

Main influence of remoteness in the energy sector is the difficulty in energy supply. Extensive rural and mountainous areas, especially in the developing world, do not have the slightest access to energy services, since these areas are the last to be electrified, under the current way in which most of the energy systems in the world work (Coello 2011; UNDP 2010). In Greece, the mountainous area of Agrafa, which is particularly isolated, was electrified in the decade of 1990. Because of the great distance from energy centers, not only electricity grids, but also the natural gas network is difficult to reach mountainous areas. Remoteness can set obstacles not only to energy supply, but also to energy export from mountainous areas. As discussed in Section 2.1.2, mountainous areas have plentiful renewable energy potential. Insufficient electricity networks and great distance from urban centers set restrictions to the energy quantities that can be exported.

The great distances from major urban and industrial centers make the transport of fuels expensive. And this is an extra burden to the households' budgets in mountainous areas. The work of Papada et al. (2016) estimated the differences in fuel prices in mountainous and remote areas in Greece. More specifically it was calculated that there is an average increase of 2% in the prices of unleaded petrol in mountainous Greece, compared to the average price in the country (for the period 2015-2016). There are certain cases of particularly remote areas, where the differences in fuel prices are greater. More specifically, in the regional unit of Evrytania (the most mountainous of Greece) and in the Municipality of Metsovo the prices of unleaded petrol were 3.4% higher than the country's average, during 2015 and 2016.

Finally, as already mentioned in Section 2.1, remoteness has a positive effect in the energy sector. In remote areas, human activities are far less than in plain areas and urban centers. So, the pressure to ecosystems is not so intense and this is of particular interest in the case of forests. The low density and intensity of human activities leads to less deforestation and so, in the presence of great forest biomass potential.

2.4 Building stock, vernacular architecture and energy

The thermotechnical characteristics of the building stock are directly connected to thermal and cooling energy needs. As a rule, older residences present lower energy performance, since they do not include good insulation and efficient energy production systems. In Greece, the first regulation related to energy performance was applied in 1979, known as Building Thermal Insulation Regulation (BTHIR). This regulation established maximum values for the thermal conductivity of structural elements (walls, roofs, floors and windows) for buildings constructed from 1980 and onwards. In 2010 the BTHIR was replaced by the Regulation for Energy Performance of Buildings (known in Greece as KENAK), which is a more integrated approach to energy in buildings. Apart from the building shell, it sets standards for the energy systems of buildings (thermal, cooling and hot water systems). KENAK is, essentially, the adaptation of Greek legislation to the 2002/91/EC Directive, which determined the obligation for setting standards, along the EU, regarding the energy performance of buildings. So, for the case of Greece an important date, regarding the energy performance of buildings is 1980, when thermal insulation, firstly, became obligatory.

There is a general feeling that in mountainous Greece, the building stock is old. This is verified by the corresponding statistical data. As shown in Table 4, in Greece 55% of residences are built before 1980. In the mountainous municipalities of Greece this percentage is 63%. In the municipalities, where over 95% of the population lives in mountain settlements, 67%, the two thirds of the residences are built before 1980. Hence, the buildings of mountain towns and villages are, to a large extent, old. This has a direct negative effect on energy performance. Taking additionally into account the cold climatic conditions, households in mountainous areas present particularly high energy demand. This makes local populations vulnerable to energy poverty, whose extent in mountainous areas will be further discussed in Section 2.5 (Katsoulakos 2011).

In addition, many mountain settlements retain their traditional character and their buildings are characterized as vernacular. In Greece, special regulations and restrictions apply in cases of vernacular settlements. The vast majority of settlements with special architectural features in the country are located in islands and mountains. Two typical examples are the regional units of Ioannina and Arcadia. According to the Ministry of Environment and Energy, about 10% of all traditional settlements of Greece are found in these areas and all of them are mountainous (DVSPM 2017). Vernacular architecture is an integral part of mountainous settlements and, in addition, it can improve their development perspectives (Giannakopoulou & Kaliampakos 2016). However, the protection of the architectural identity can set restrictions to the energy upgrade of residences. For instance, it may not be easy to combine external thermal insulation or installation of solar energy systems with retaining vernacular architecture. Bearing in mind the old building stock of mountainous settlements and their great energy demand, increasing energy efficiency is definitely a priority. So, restrictions in applying energy saving measures in buildings is an obstacle for increasing energy efficiency in mountainous areas.

In Greece, there are many cases of mountain settlements, in which the installation of solar energy systems is not allowed, in order to protect their architectural identity. An example, where solar systems are not allowed to be installed in buildings is the mountainous town of Metsovo. It has been estimated that up to 1,200,000 kWh of energy could be saved if solar systems could be used in this town (Katsoulakos 2013). The energy loads in Metsovo, as already mentioned, are particularly high (over 20 MWh/year) because of the cold climate. So, the inhabitants despite the legal restriction have begun to install solar systems, in order to avoid some energy costs. It is obvious that an integrated plan should be created, in order to provide local societies with solutions that can combine vernacular architecture with modern

Table 4 Distribution of residences in Greece, with respect to the construction period (ELSTAT 2017)

	Distribution of residences (%)			
	before 1960	1961-1980	1981-2000	after 2001
Across Greece	17	38	29	16
Mountain Municipalities	33	30	26	11
Mountain Municipalities with more than 95% of population in mountain settlements	38	29	26	7

energy systems. In Figure 6, a good example of combining vernacular architecture with solar systems can be seen. The solar thermal panels have been positioned on the roof and there is no external boiler, like in many applications in Greece, which can be a major distortion in a building's aesthetics.

Figure 6 A good example of including solar thermal systems in a building that follows vernacular architecture patterns in a mountainous village in the regional unit of Arcadia, Greece.

2.5 Lack of productive activities and energy

The lack of plain, productive areas and the cold climatic conditions set obstacles to agricultural production in mountainous areas. Livestock breeding – that used to be a main productive activity – is declining, since traditional pastoralism is being replaced by industrialized livestock breeding. Because of remoteness and small population density, the industrial activity in mountainous areas is very low. In the tertiary sector, only tourism is a significant productive activity that enhances development opportunities of mountainous areas (Katsoulakos 2013). Therefore, there is a lack of productive activities in mountainous areas and the employment opportunities are particularly restricted. This makes the majority of the world's mountainous areas vulnerable to poverty. About 39 percent of the mountain population in developing countries, or 329 million people, is estimated to be vulnerable to food insecurity, according to the United Nations (UN 2017). In Greece, the most mountainous Region, the Region of Epirus is simultaneously the poorest one. The most mountainous regional unit, the regional unit of Evrytania, has the lowest GDP per capita. All the mountainous areas of Greece are characterized as less-favored areas in the EU 85/148 Directive. According to the Greek Statistical Authority (ELSTAT), the average annual income of households in mountainous municipalities, in 2011, was 14.915 €. Compared to the country's average, for the same year, the annual households' income of mountainous municipalities is 35% lower.

The lack of productive activities, which leads to lower incomes in mountainous areas has profound impact on the energy sector. Low incomes, combined with high thermal loads and low energy efficiency of buildings expose mountain population to the problem of energy poverty. This claim is verified by relevant research findings, which are particularly worrying for the case of Greece. Three primary surveys were conducted in Greece in 2015 in order to study the issue of energy poverty, in which the authors of the present paper took part. Considering as energy poor households that spend more than 10% of their income for energy expenses, the surveys showed that 73.5% of mountain households are energy poor. The corresponding percentage at country level is 58%. Almost 46% of the households in mountainous areas reported leakages and vapor condensation problems in their dwellings and 38% stated that their homes are not adequately heated (Kaliampakos 2015, Papada & Kaliampakos 2017). These findings imply that energy poverty is not just a risk for Greek mountainous areas, but part of their socioeconomic landscape, especially under the influence of the economic crisis.

Another dimension of the lack of productive activities in mountainous areas is related to the energy sector; the importance of creating new employment opportunities, new workplaces. Energy investments can create new workplaces. Renewable energy units utilizing the plentiful energy potential of mountainous areas can help towards this direction, as well as investments in energy efficiency. The studies of Tourkolias & Mirasgedis (2011) and Mirasgedis et al. (2014) quantified in monetary terms the employment benefits of investments in renewable energy and energy efficiency. The employment benefits are particularly important and mountain societies can improve their development perspectives if such investments are promoted. Biomass energy is of particular importance for mountainous areas, since by biomass combustion thermal energy can be primarily produced. According to the aforementioned studies, biomass has the highest employment benefits, among the most commonly used renewable energy sources, in the operational phase of the energy units. In addition, energy efficiency interventions (which are also crucial for mountain areas, because the lead to reduction in energy demand) also present positive impacts to employment and the economy, in general. It is important that two forms of energy investments that suit to the energy profile of mountainous areas, simultaneously, present high external economic and social benefits. However, the positive social impacts of energy projects are influenced, at a large extent, by the model which is followed for developing renewable energy sources. For instance, under the current liberalized model of the energy market, decentralized renewable energy units for covering local energy needs are not promoted and this deprives mountain societies of employment opportunities and revenues (Reddy 2002).

3 Conclusions

The present paper attempts to delineate the energy identity of mountainous areas using Greece as a case study. The analysis made makes clear that the special features of mountainous areas are associated with the energy sector. The particular identity of mountainous areas affects aspects related to the energy sector and, consequently, energy planning. We are in a period, in which energy markets change. Various technological solutions and market schemes are introduced in energy planning. Decentralized energy production and further use of micro-grids may be one of the trends in energy policy within the next years. Understanding well local characteristics, which affect energy planning – such as the energy identity of mountainous areas – is an important step towards optimizing decentralized energy planning and finding beneficial solutions for local societies.

Trying to summarize the issues presented in the previous Sections, the following notes can be pointed out:

- Energy demand: The influence of altitude on climate increases significantly thermal energy demand in mountainous areas, whereas the cooling loads are lower than in lowland areas.
- Energy potential: Mountain climate and topography, as well as remoteness, result in the existence of plentiful renewable energy potential in mountainous areas, which is an important resource.
- Social impacts: Under the influence of high thermal loads and low energy performance (because of the old building stock) and in combination with low incomes, mountain societies are particularly exposed to energy poverty. Moreover, the great energy needs of mountainous settlements result in an increase in their environmental footprint.
- Restrictions and needs: The lack of space in the steep mountain slopes sets obstacles to sitting energy projects. The great distance between mountainous areas and major urban/ industry centers makes the expansion of energy grids and the transport of fuels expensive. Vernacular architecture is not always easy to be combined with modern energy technologies and energy saving interventions. Because of the lack of productive activities in mountainous areas, employment opportunities are very important and so, new investments in the energy sector can improve the development perspectives of mountain areas. The great thermal loads make energy efficiency crucial factor for energy planning in mountainous settlements.

In Figure 7, the characteristics of mountain energy identity are summarized, in order to have a supervisory view of it.

Taking the energy identity of mountainous areas into account, the basic target of specialized mountain energy policy should be sufficient and affordable energy supply, in other words energy poverty alleviation. In order to achieve this target, energy policy for mountainous areas should include:

- The promotion of energy efficiency interventions should be set as a priority.
- The utilization of the plentiful renewable energy potential, but under a policy framework that does not exploit mountain resources just for the benefit of energy enterprises and/or other areas. The utilization of mountain renewable energy sources should provide local societies both with new employment opportunities and appropriate compensatory benefits, which will boost local economies and reduce the impacts of energy poverty.
- Decentralized energy production, with special attention on participatory funding schemes

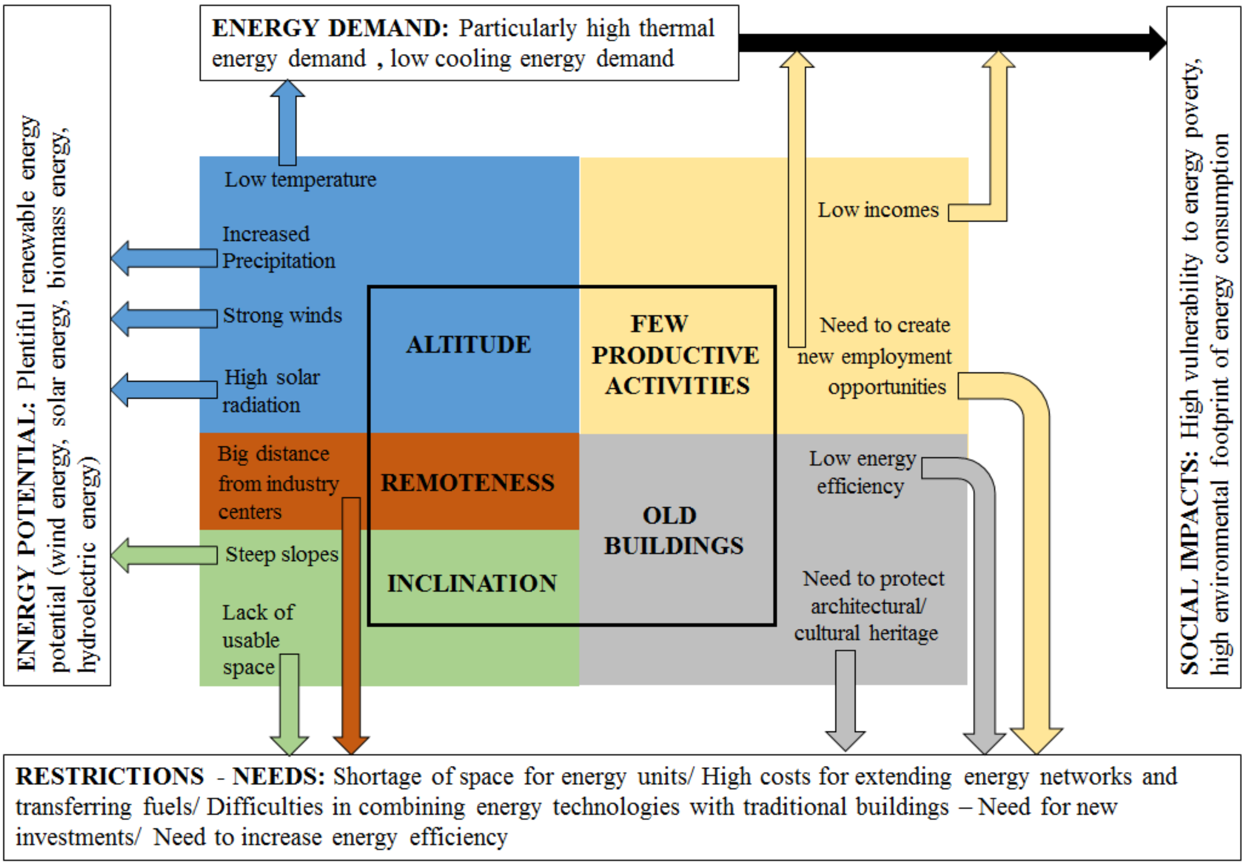

Figure 7 Synopsis of the energy identity of mountainous areas.

is, since energy cooperatives start to be promoted across the EU and they can help mountain societies utilize local resources to their own benefit.

- The lack of plain space, combined with the need to decrease thermal energy demand could lead to policies and solutions, related to the utilization of underground space. For instance, underground dwellings or underground tourist facilities could be an innovative solution leading to more effective space utilization and reduction in energy loads (Benardos et al. 2014).

As regards Greece, the marginalization of mountainous areas and so, the insufficient study of their energy issues led to measures and policies that did not take into account the special needs and problems of local societies. Funding mechanisms that promoted energy efficiency, as well as policies for subsidizing heating fuel have not taken into account the high thermal loads of mountainous settlements and the low incomes of their inhabitants (Katsoulakos & Kaliampakos 2014). Since 2016 some small steps were made in the direction of reversing this situation. More specifically, the initial mistakes made in the planning of heating fuel subsidies were corrected and subsidies for higher fuel quantities were given to many mountainous areas. Moreover, in the end of 2017, the Government provided mountain populations with an extra “social dividend”, aiming at supporting them to cover part of their increased energy costs. However, the new supporting mechanism for energy saving interventions in the residential sector (planned to run in 2018 – called “energy saving II”) does not take into account the high thermal loads of mountainous settlements.

The rejuvenation of mountainous areas and the improvement of their future perspectives should include sustainable energy planning as a core part. The present paper aspires to offer insight to parts of the energy issues of mountainous areas and help towards forming specialized and effective energy policy for them.

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