Vulnerability assessment of energy demand due to climate change in Cyprus

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Abstract

The purpose of this study is to investigate the impacts of climate change on future energy requirements in the built environment in Cyprus using both daily temperature projections from a regional climate models and the Degree Day indicator to examine heating and cooling demand in the near future. In the first case, using daily energy consumption data for the present climate, we construct an impact model linking consumption and temperature and assuming the same technology use we project this relationship to the future climate using the RCMs data. In the second case, using the indicator of Degree Day (DD) we examine the changes on energy demand needed to heat or cool a building in the near future.

Keywords

Climate change, energy demand, Impacts, adaptation, vulnerability

Energy consumption and temperature

Weather fluctuations have a significant impact on different sectors of the economy. One of the most sensitive is the energy market, because power consumption is linked to several weather variables (mainly air temperature). Consumption of energy is particularly sensitive to weather, since large amounts of energy cannot be stored and thus energy that is generated must be instantly consumed. Daily energy consumption in countries throughout the world shows a clear seasonal pattern. Average daily energy consumption in most European countries, historically shows a single peak during winter months. Only the European Mediterranean countries show an additional peak during summer months (Giannakopoulos and Psiloglou 2006). Consumption patterns with only summer peaks may be found outside of Europe.

Hourly electricity consumption data together with mean daily air temperatures for the island of Cyprus were made available by the Transmission System Operator of Cyprus. These data refer to total hourly residential and commercial electricity consumption (MWh) spanning the period from January 1999 to December 2009.

Daily variation in air temperature and electricity consumption for the period 1999–2009 for the island of Cyprus is depicted in Figure 1. Electricity consumption shows a clearer upward trend than does air temperature. The increase in electricity consumption is largely due to economic growth and also to greater usage of air conditioners in residential and commercial situations. The link between hot weather and increased electricity consumption is also evident in other warm countries where use of air conditioners has increased. It is obvious that there are two components in electricity load variations: seasonal and yearly. The former is mainly influenced by the prevailing weather conditions and the latter by economic, social and demographic factors.

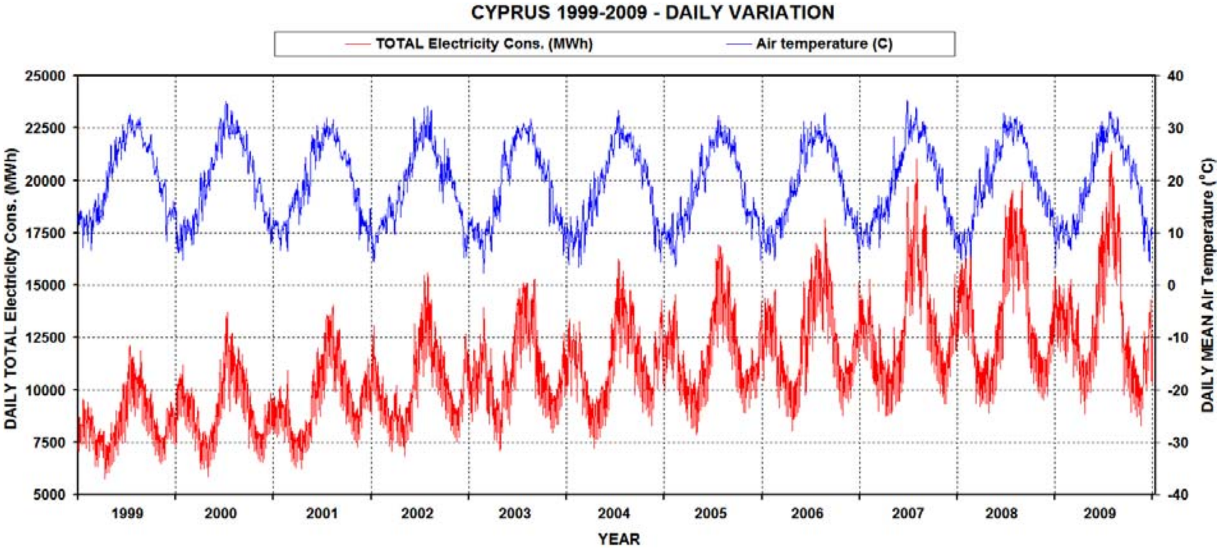


Figure 1: Daily variation in air temperature (ºC) and electricity consumption (MWh) for the period 1999–2009 for the island of Cyprus.

Variation in daily electricity consumption and mean daily air temperature for the examined period 1999-2009 is shown in Figure 2. Electricity consumption is closely linked to mean daily air temperature; the maximum values of the former coincide with extremes of the latter. In January, electricity consumption peaks during the lowest temperatures. In the transitional season (March–April) when air temperatures are constantly rising but remain comfortable, electricity consumption levels are approximately constant. Electricity use is greatly reduced during weekends and holidays compared to working days. The lowest values of electricity consumption occur during the long Easter weekend (Good Friday to Easter Monday) and other fixed holidays (Christmas, bank holidays, Assumption Day), irrespective of daily mean air temperature. The relationship between electricity consumption and air temperature is not linear, but presents a single minima and double maxima. Above this minima, electricity consumption increases with higher temperatures (due to air conditioning). Below this minima, electricity consumption increases with lower temperatures (due to space heating)

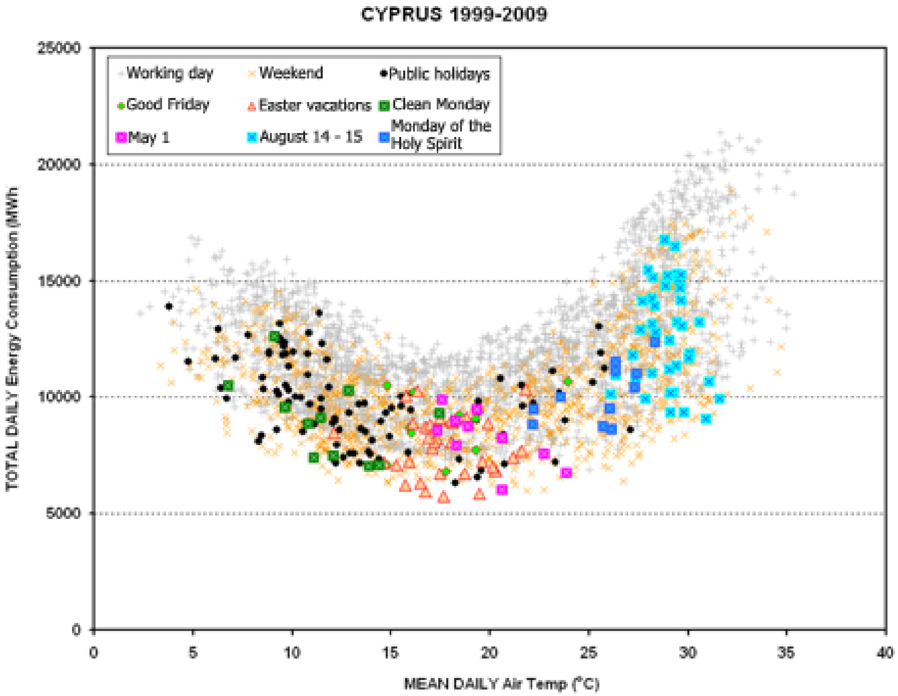


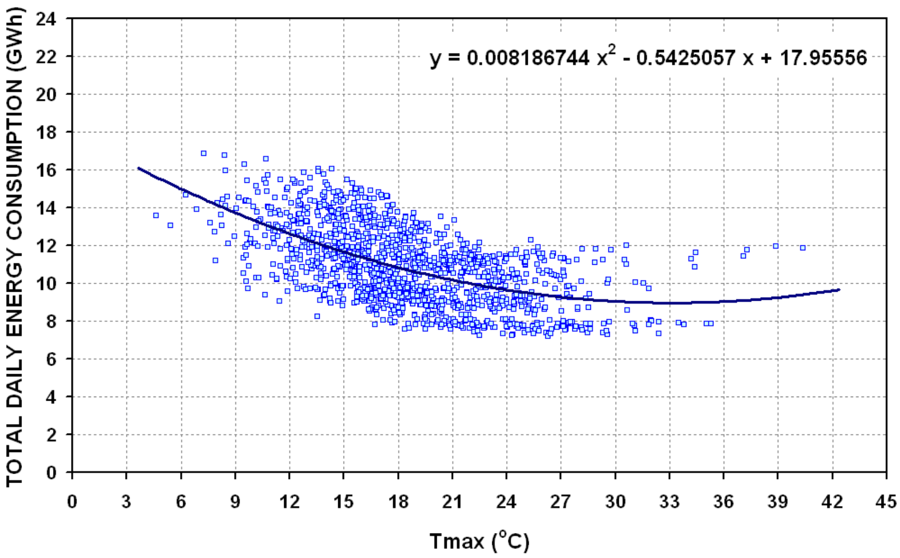
Figure 2: Scatter plot of daily electricity consumption versus daily mean air temperature for the period 1999–2009 for the island of Cyprus. Working days and weekends/holidays have been plotted using different shape figures.

Future electricity consumption levels

The electricity consumption is linked to climatic conditions and it is expected that with warmer weather, decreased consumption should be typical in winter and increased consumption should be typical in the summer. Moreover, the effect of higher temperatures chiefly in summer is likely to be considerably greater on peak electricity consumption than on net consumption, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth.

For the investigation of future electricity consumptions in relation to temperature rises, temperature data from the PRECIS RCM as well as the 6 ENSEMBLES RCMs are used for two 30 yr periods: the 'control period' 1961–1990 and the 'future period' 2021-2050, employing the A1B scenario. To be able to project electricity consumption under future climatic conditions, the same technology use is assumed between the control and the future period. Moreover, we split our examined period into 'cold' and 'warm' period. The 'cold' period covers the months November-April and the 'warm' period the months May-October.

The variation of electricity consumption in the 'cold' period follows a non-linear decreasing pattern as temperatures rise and the mathematical formula used for the extrapolation under future climatic conditions appears in Figure 3(a). Figure 3(b) presents patterns of electricity consumption related to maximum air temperature for the observations (1999-2009), the control period 1961-1990 and the future period using the extrapolation formula of Figure 3(a). For the 'cold' period of the year (November to April), a decreasing trend in electricity consumption is evident as warmer conditions dominate by 2050. Moreover, it is clear that observations lie closer to the levels of consumption typical in the 2021-2050 than in 1961-1990, indicating that a certain degree of decrease in electricity consumption levels in the 'cold' period of the year has already occurred by 2009. There are variations among the various examined models but the signal of decrease around 5% compared to the control period in electricity consumption levels remain.



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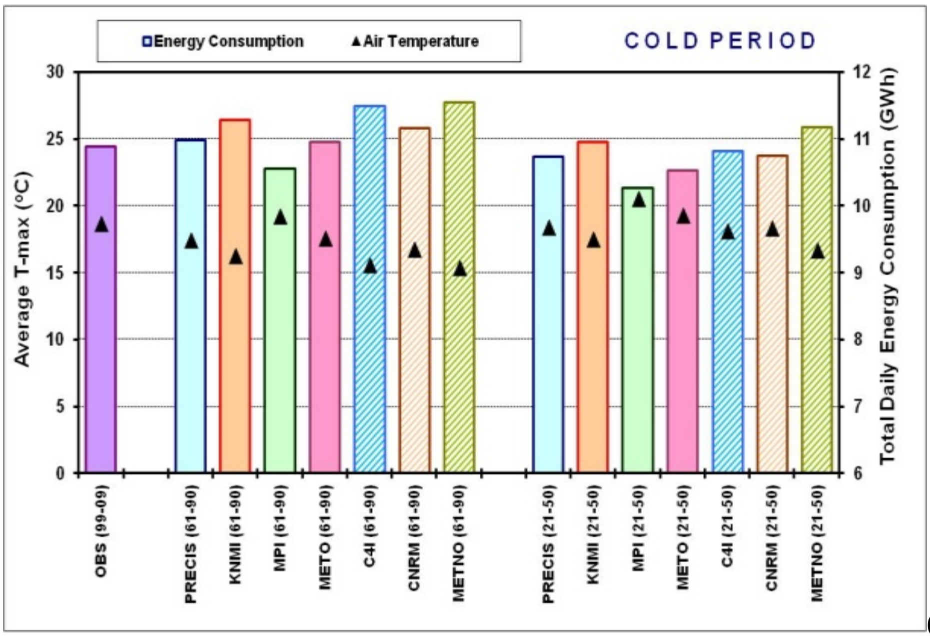
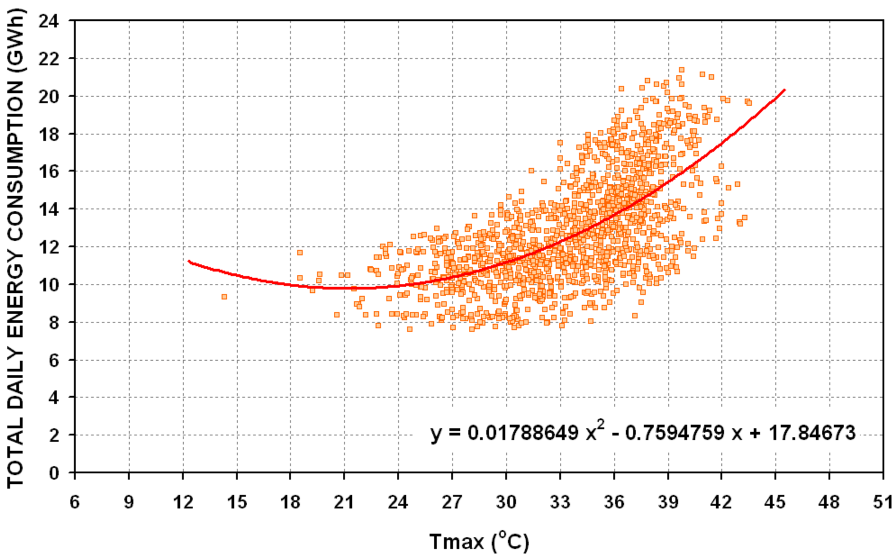


(b)

Figure 3: (a) Relation of daily electricity consumption with daily maximum air temperature for the 'cold' period of the year for the period 1999-2009 in Cyprus. (b) Cyprus electricity consumption (bars, right axis) and daily maximum air temperature (triangles, left axis) for the 'cold' period of the year for the observations period 1999-2009, the various models for the control period 1961-1990, and the future period 2021-2050.

The variation of electricity consumption in the 'warm' period follows a non-linear increasing trend as temperatures rise and the mathematical formula used for the extrapolation under future climatic conditions appears in Figure 4(a). Figure 4(b) presents patterns of electricity consumption related to temperature for the observations (1999-2009), the control period 1961-1990 and the future period using the extrapolation formula of Figure 4(a). For the 'warm' period of the year (May-October), an increasing trend in electricity consumption is evident as warmer conditions dominate by 2050. Moreover, it is clear that observations lie closer to the levels of consumption typical in the 2021-2050 than in 1961-1990, indicating that a certain degree of increase in electricity consumption levels in the 'warm' period of the year has already occurred by 2009. There are variations among the various examined models but the signal of increase around 10% compared to the control period in electricity consumption levels remain. It is worth noting here that the increase in the 'warm' period of the year doubles the electricity decrease (saving) in the 'cold' period of the year.



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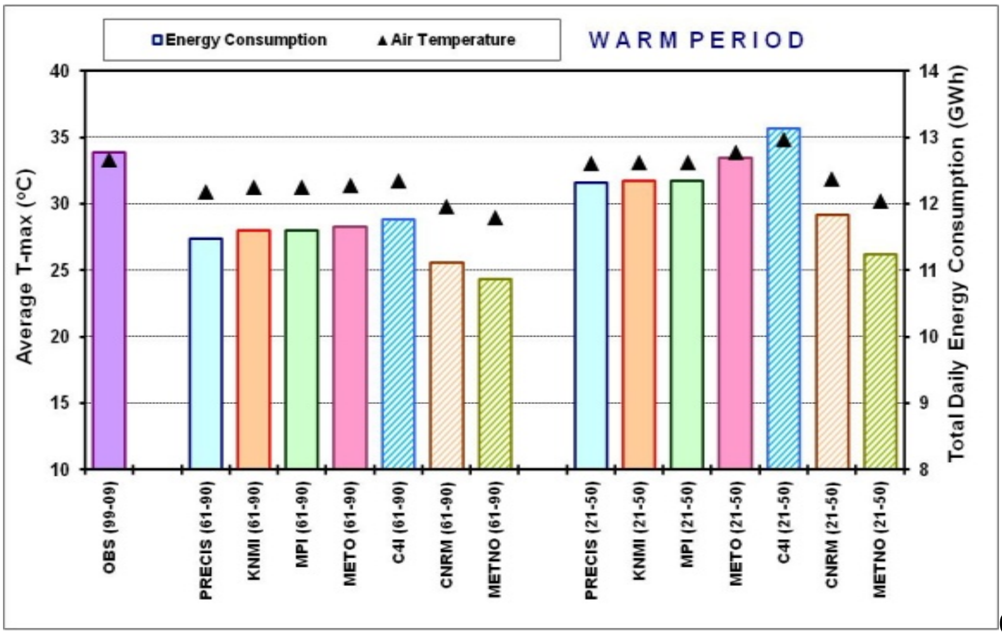

(b)

Figure 4: (a) Relation of daily electricity consumption with daily maximum air temperature for the 'warm' period of the year for the period 1999-2009 in Cyprus. (b) Cyprus electricity consumption (bars, right axis) and daily maximum air temperature (triangles, left axis) for the 'warm' period of the year for the observations period 1999-2009, the various models for the control period 1961-1990, and the future period 2021-2050.

Degree – day Indicator

To further investigate future impacts of climate change on energy sector in Cyprus the indicator of Degree-Day (DD) is used. Degree Day is a measurement designed to reflect the demand for energy needed to heat or cool a building. It is defined as the difference of the mean daily outdoor temperature from the base temperature. Base temperature is the temperature above or below which a building presents no requirements for heating or cooling, respectively. In other words, base temperature is usually an indoor temperature which is adequate for human comfort. Degree-Days are categorized into Heating Degree Days (HDD – demand for heating) and Cooling Degree Days (CDD – demand for cooling). For the calculation of the HDD and CDD indices, the following equations were used:

$$HDD = \max(T^* - T, 0)$$

$$CDD = \max(T - T^{**}, 0)$$

where T^* and T^{**} are the base temperatures for HDD and CDD respectively, which can be either the same or different and T is the mean daily temperature calculated from the daily data of the RCM for both the control – reference period (1961 – 1990) and the future (2021 – 2050) period.

In our study we used 15°C as base temperature for the calculation of HDDs and 25°C for the calculation of CDDs. We identified the changes in energy demand levels by showing differences in the cumulative numbers of CDDs and HDDs between the reference (1961–1990) and the near future (2021 – 2050) period. All calculations were performed using the PRECIS Regional Climate Model (RCM).

Heating Degree Days

Spring is generally a transient season in which energy demand levels are kept nearly constant and at low levels. Due to warmer climate conditions a decrease is anticipated in energy demand both during spring and winter which can be considered as a "positive aspect" of climate change in Cyprus. Figure 5(a) shows cumulative HDD during spring for control period using PRECIS RCM. It is shown that inland and southeastern areas present an energy demand for heating of about 90 and 50 degree-days respectively. Southern and western areas present an energy demand of around 100 degree-days. The maximum energy demand is presented at high elevation areas of Troodos Mountain varying from 130 to 225 degree-days. As far as future changes are concerned, Figure 5(b) depicts that energy demand during spring is projected to decrease in all Cyprus. The greater reductions are projected for mountain areas of about 75 degree-days. For inland and southeastern areas, although the demand is small, it is projected to drop further in the near future of about 25-30 degree-days. For southern and western areas the decrease is expected to reach 30 degree-days.

In Cyprus, the greatest energy demand for heating is observed during winter months. As shown in Figure 5(c), control period energy demand for heating reaches 650 degree-days mainly in the wider area of Troodos Mountain and approximately 350 degree-days in western and 450 degree-days in southern-southeastern and inland regions. Significant reductions in energy demand due to warming conditions are projected for the near future for almost all the island. Figure 5(d) depicts that mountain regions (from high to medium elevations) will benefit most from the greatest reductions of about 90 degree-days. Furthermore for inland, south-southeastern and western areas the reduction is approximately 60 degree-days.

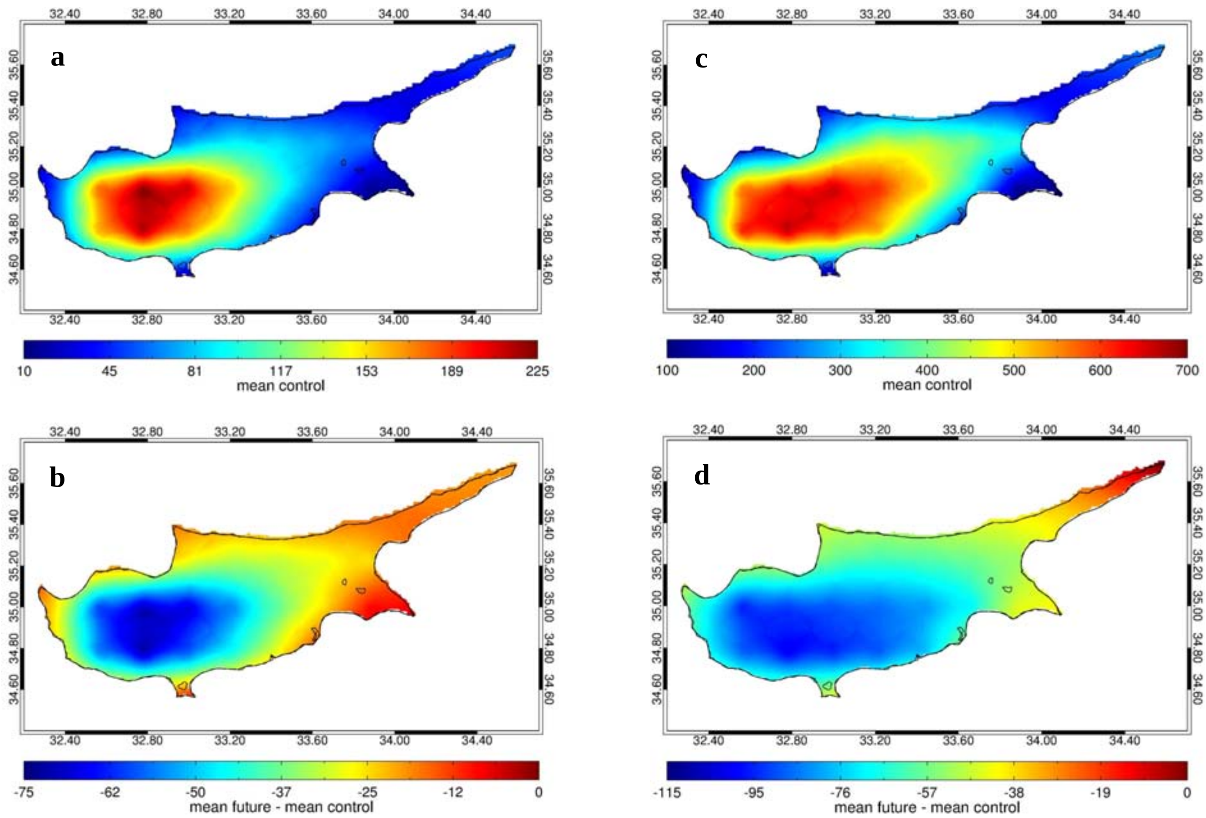

Figure 5: (a) Spring cumulative HDD for control period (1960-1990), (b) Change in spring cumulative HDD in the near future (Future – Control), (c) Winter cumulative HDD for control period (1960-1990), (d) Change in winter cumulative HDD in the near future (Future – Control).

Apart from seasonal distribution of energy demand for heating, it has also been studied the annual distribution of it. As Figure 6(a) shows, the pattern of distribution is similar with the respective patterns of the previous seasonal plots. It is depicted that maximum energy demand for heating of about 950 degree-days derives from high elevation areas (Troodos Mountain). In addition inland, southeastern as well as southern and western areas present lower energy demand of about 550 degree-days. The “beneficial impacts” of warming in the future are shown in Figure 6(b) where a significant reduction of energy demand for heating of about 200 degree-days in the wider area of Troodos Mountain is testified. Also, inland, southeastern and western areas show a reduction of about 110 degree-days.

Finally, Figure 6(c) shows the number of days per year requiring heavy heating i.e. days requiring heating of more than 5°C from the base temperature of 15°C. It is also shown that mountain regions of Troodos demand approximately 100 days of heavy heating while inland and southern areas require approximately 55 days. Southeastern and western regions require fewer days for heavy heating of the order of 35. Regarding projections on future changes, Figure 6(d) shows a decrease in the number of days per year requiring heavy heating. In particular, a decrease of about 18 days is projected for mountain region while for Nicosia and Limassol Districts the decrease is about 12 days. Also, southeastern and western areas show a reduction of about 10 days.

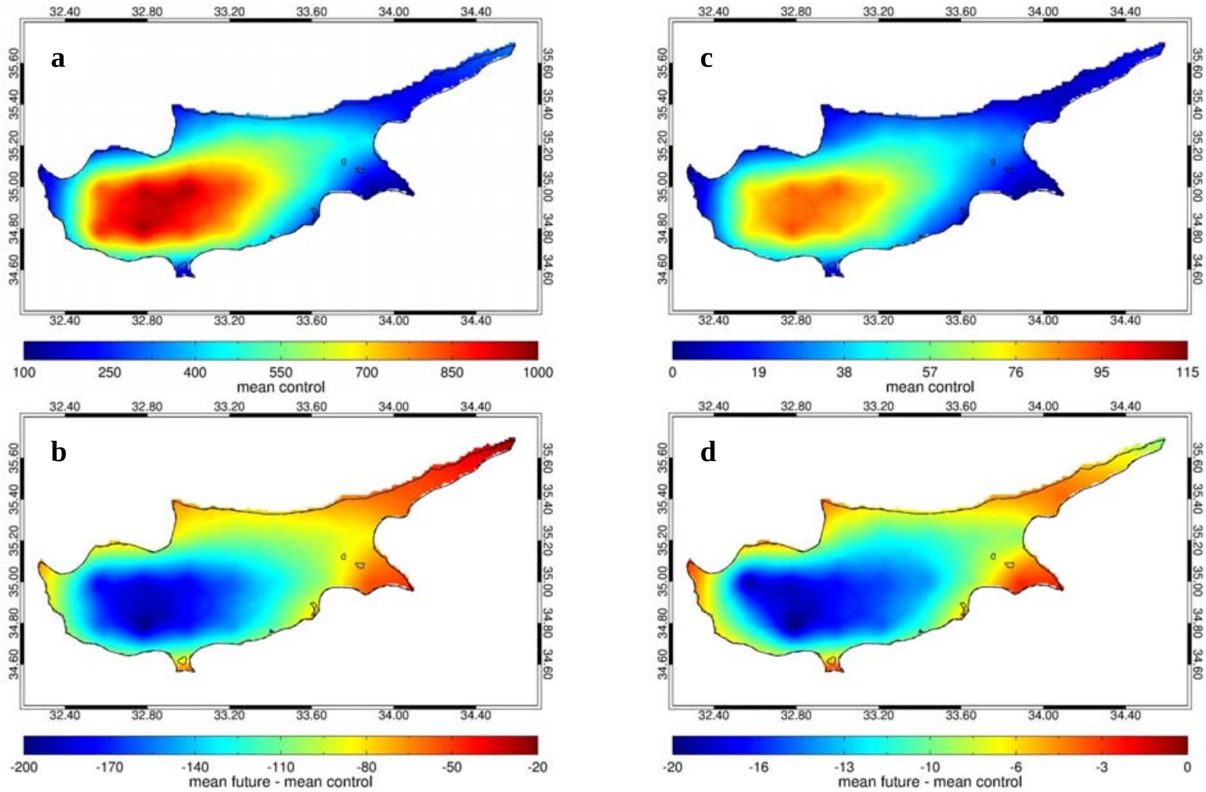

Figure 6: (a) Annual cumulative HDD for the control period (1960-1990), (b) Change in annual cumulative HDD in the near future (Future – Control), (c) Number of days with high HDD (>5 °C)) for the control period (1960-1990), (d) Change in the number of days with high HDD (>5 °C) in the near future (Future – Control)

The overall findings of the analysis regarding both present-day climate and potential near future changes due to climate change with negative or positive impacts on Cyprus energy demand for heating are summarized in Table 1

Table 1: HDD for control period as well as future changes (future – control) due to climate change in Cyprus.

	Western Regions		Mountain Regions		Inland Regions		Southern Regions		Southeastern Regions	
	Control	Change	Control	Change	Control	Change	Control	Change	Control	Change
Spring Cumul. HDD	100	(-) 30	130-225	(-) 75	90	(-) 25	100	(-) 30	50	(-) 25
Winter Cumul. HDD	350	(-) 60	650	(-) 90	450	(-) 60	450	(-) 60	450	(-) 60
Annual Cumul. HDD	550	(-) 110	950	(-) 200	550	(-) 110	550	(-) 110	550	(-) 110
Nb of days with high HDD (>5)	35	(-) 10	100	(-) 18	55	(-) 12	55	(-) 12	35	(-) 10

Cooling Degree Days

To begin with, Figure 7(a) depicts current energy demands during summer using PRECIS model. It is testified that greater energy demands for cooling, of around 300 degree-days are presented in southeastern (Larnaca District) and inland (Nicosia District) regions. Lower energy needs are shown in mountain and much lower in western regions where energy demands reaches 100-200 degree-days and 50-100 degree-days respectively. As far as future changes are concerned, Figure 7(b) shows that an extended increase in energy demand of about 160-200 degree-days for mountain regions and about 200 degree-days in inland and southern – southeastern areas is anticipated. Fewer energy needs are projected for western areas of the order of 100 degree-days.

Regarding the possibility of warming influencing energy demand during autumn, the fall cumulative cooling degree-days parameter has been examined. Figure 7(c), presents that in the present-day climate, energy demand for cooling during the autumn is at low levels, 30 degree-days with most demand being confined at southeastern and inland regions. Western regions shows lower energy demands of about 10 degree-days. Concerning future changes, Figure 7(d) shows a rise in energy demand of about 50 degree-days in inland and southeastern regions and about 40 degree-days in southern regions. For mountain and western regions the increase is lower of around 30 and 20 degree-days respectively.

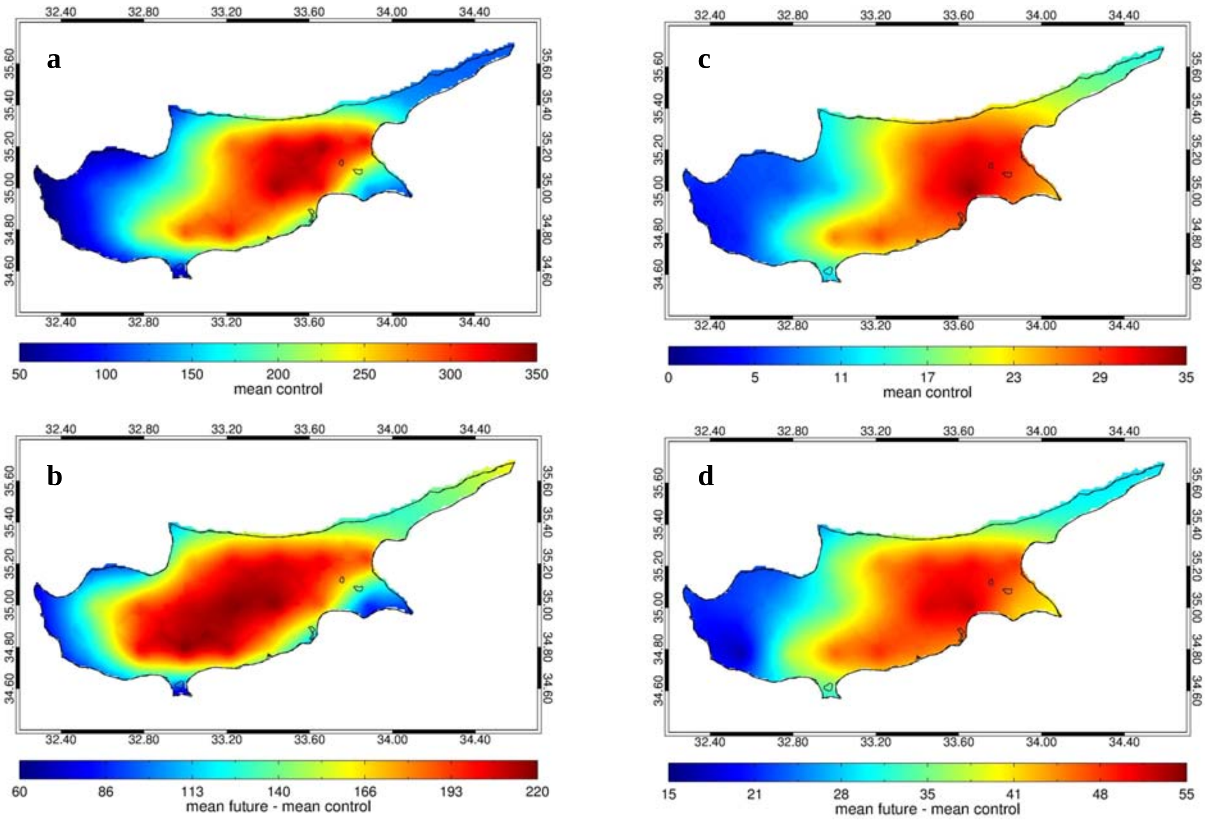

Figure 7: (a) Summer cumulative CDD for the control period (1960-1990), (b) Change in summer cumulative CDD in the near future (Future – Control), (c) Fall cumulative CDD for the control period (1960-1990), (d) Change in fall cumulative CDD in the near future (Future – Control)

To examine the annual pattern of energy demand for cooling, annual cumulative CDD parameter has also been investigated. Figure 8(a) depicts that in the present-day climate, the yearly maximum energy demands of about 350 degree-days are derived from southeastern and inland regions while mountain and western regions shows lower demands of about 200-260 degree-days and 100 degree-days respectively. Concerning future changes according to PRECIS projections, Figure 8(b), shows an important increase of about 260 degree-days for inland, southern and southeastern regions. In mountain areas the increase varies from 170 to 260 depending on the altitude. Only the western part of the island is expected to experience lower increases of about 100 degree-days.

Finally, an important parameter in assessing the changes in energy demand for cooling was examined, namely the number of days per year requiring excessive cooling of more than 5°C from the base temperature of 25°C. Figure 8(c) shows that, nowadays, it is required 25-30 days per year of heavy cooling mainly in southeastern and inland regions as well as southern regions (Limassol). In mountain and western regions the number of days with heavy cooling is around 5-15 days and 0-5 days respectively. Regarding future changes, Figure 8(d) shows that it is anticipated an additional month of heavy cooling in the near future period for inland, southern and southeastern regions. In mountain regions the increase varies from 15 to 30 days depending on the height. For western regions a smaller increase of about 5 days is expected.

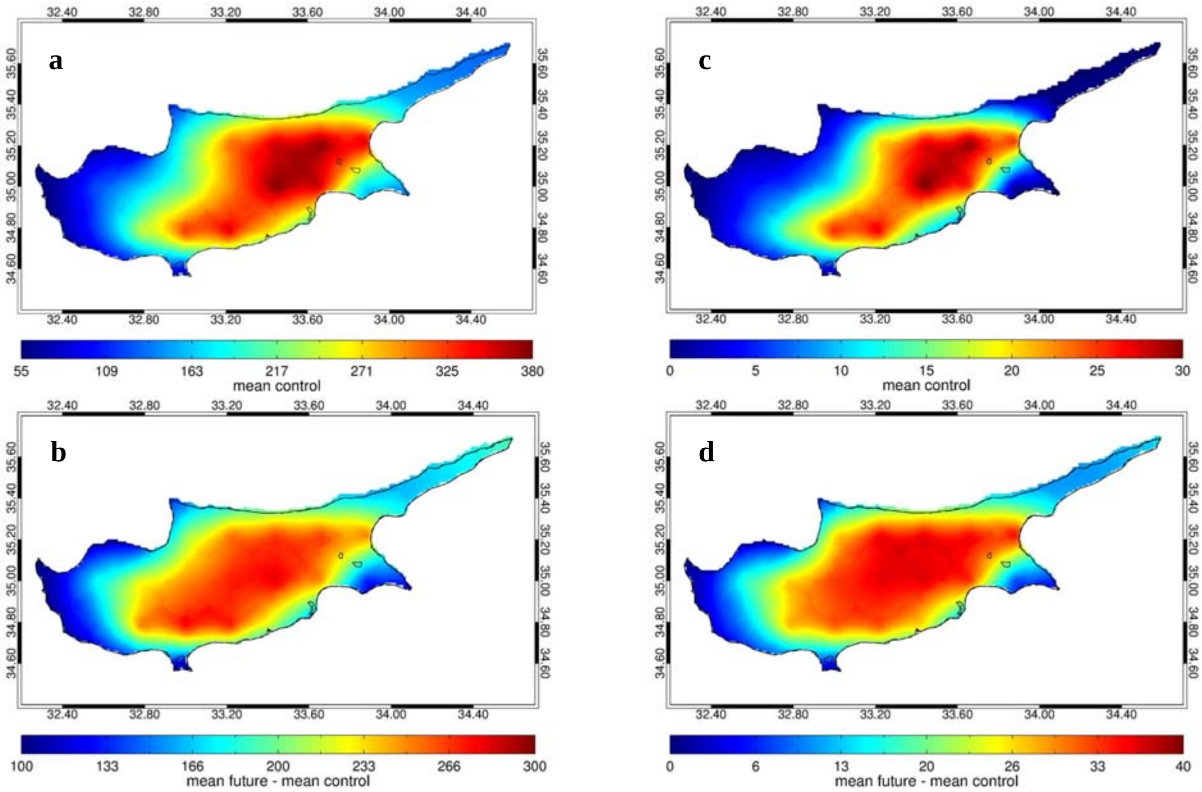

Figure 8: (a) Annual cumulative CDD for the control period (1960-1990), (b) Change in annual cumulative CDD in the near future (Future – Control), (c) Number of days with high CDD (>5 °C) for the control period (1960-1990), (d) Change in the number of days with high CDD (>5 °C) in the near future (Future – Control).

The overall findings of the analysis regarding both present-day climate and potential near future changes due to climate change with negative or positive impacts on Cyprus energy demand for cooling are summarized in Table 2.

Table 2: CDD for control period as well as future changes (future – control) due to climate change in Cyprus.

	Western Regions		Mountain Regions		Inland Regions		Southern Regions		Southeastern Regions	
	Control	Change	Control	Change	Control	Change	Control	Change	Control	Change
Summer Cumul. CDD	50-100	(+) 100	100-200	(+) 160-200	300	(+) 200	150-250	(+) 200	300	(+) 200
Fall Cumul. CDD	10	(+) 20	10-20	(+) 30	30	(+) 50	20	(+) 40	30	(+) 50
Annual Cumul. CDD	100	(+) 100	200-260	(+) 170-260	350	(+) 260	190-220	(+) 260	350	(+) 260
Nb of days with high CDD (>5)	0-5	(+) 5	5-20	(+) 15-30	25-30	(+) 30	10-20	(+) 30	25-30	(+) 30

Taking into account both the future changes in annual energy demand for cooling (CDD) and in annual energy demand for heating (HDD) in Cyprus, it can be said that most pronounced is the effect of increased demand for cooling in the inland regions (Nicosia) and southern and southeastern coastal regions (Limassol, Larnaca and Famagusta). In particular, the difference between the annual CDD and HDD is 150 days, while for the mountain regions (Troodos) and western regions (Paphos) the difference is minor (**Error! Reference source not found.**).

Table 3: Future changes in accumulative annual HDD and CDD in Cyprus

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
Change in accumulative annual HDD (A)	(-)110	(-)200	(-)110	(-)110	(-)110
Change in accumulative annual CDD (B)	(+)100	(+)215	(+)260	(+)260	(+)260
Difference (A)-(B)	(-)10	(+)15	(+)150	(+)150	(+)150

Given that the areas projected to be mostly affected by increases in temperature and especially Nicosia which is the capital of the island are densely populated, as well as that the free area of Famagusta constitutes a highly touristic area with excess demand for cooling in the summer period, while the mountain areas are more sparsely populated, the exposure of heating/cooling demand to climate changes has been ranked as very high.

Assessment of adaptive capacity

The adaptive capacity of the sector to changing demand in power and heat is dependent on the following four aspects:

- Installation of new power plants for following future energy demand of the island;
- Energy efficiency measures undertaken or underway;
- Use of solar energy for heating and cooling. In Cyprus, solar thermal systems are widely used for the needs for hot water, while photovoltaic systems are increasingly used at household level reducing therefore the pressure on the energy supply sector; and
- Introduction of natural gas in the energy supply portfolio.

New power stations

- **Maximum output capacity (2016):** **~1,700 MW**
- **Peak demand (2016):** **~1,400 MW**
- **Energy capacity (2020):** **7,360 GWh**

In order to assess the sensitivity of the sector regarding the changing demand for electricity and heat a series of additional indicators should be taken into consideration, as for instance energy dependence of the island on imports.

First of all, the main sensitivity lies in the capacity of supplying the ever increasing demand for electricity, which is partly attributed to economic and development factors as well as to climate change (mainly temperature increase). The electrical requirements are expected to grow over time, fact that requires the installation of new power plants (EAC, 2011).

It must be noticed that, while there exists a sufficient follow-up between supply and demand, meaning that EAC has developed a plan to guarantee the succesfull delivery of power in order to meet the increasing demand (lowering down the sensitivity), there is a sustained challenge which needs to be addressed. The current electricity production regime is dependent on imported oil, fact that implies concern over the energy dependence of the island, which in turn implies questions about how secure is the energy system and capable of delivering electrical energy whatever the external political and economic circumstances.

The primary energy consumption of Cyprus is dependent highly in petroleum products[1], the cost of which totaled to 3 billion € corresponding to 19.7% of the total cost on imports or 7.3% of the GDP of the Republic of Cyprus. The same does not apply for EU-27 and the globe.

Energy efficiency measures

Cyprus has established a National Energy Efficiency Action Plan, which involves the implementation of a set of measures for improving energy efficiency until 2020. The indicative intermediate target for 2016 was set at 185,000 toe[2], while the contribution by sector is as follows (MCIT, 2011):

- Residential sector: 161,877 toe (87.5%);
- Tertiary sector (public sector, general government and enterprises): 23,681 (12.8%);
- Industrial sector: 1,284 toe (0.69%) and
- Transport sector: 3,909 toe (2.11%).

Natural gas introduction

In order to diversify the energy supply mix, a policy measure which shall be soon undertaken is the introduction of natural gas. By 2014 new gas-fired plants are scheduled to operate. The use of natural gas in power generation is estimated to lead savings of up to 271,000toe (MCIT, 2011).

On the 28th of December 2011 Noble Energy announced the discovery of natural gas at the Cyprus Block 12 prospect, offshore the Republic of Cyprus as a result of the 1st licensing round for hydrocarbon exploration in its EEZ. The Cyprus A-1 well encountered approximately 310 feet of net natural gas pay in multiple high-quality Miocene sand intervals. The discovery well was drilled to a depth of 19,225 feet in water depth of about 5,540 feet. Results from drilling, formation logs and initial evaluation work indicate an estimated gross resource range of 5 to 8 trillion cubic feet (Tcf), with a gross mean of 7 Tcf. The Cyprus Block 12 field covers approximately 40 square miles and will require additional appraisal drilling prior to development.

The discovery of indigenous gas reserves is anticipated to lead to a redesign of the gas sector structure in Cyprus and revisions of policies, political decisions and schedules would have to be done.

Natural gas is estimated to be available in Cyprus' domestic market approximately in 2016.

Since after the discovery of the natural gas field, there have been changes in the policy of the Republic of Cyprus. More particularly, even if it was initially considered to transport the natural gas to the onshore receiver terminal at Vasilikos in liquefied form, it is unclear whether this option comprises an alternative today or not.

The natural gas demand is projected to rise. It is expected that the introduction of natural gas in the energy mix will provide a diversified, safer energy profile for Cyprus and that will gradually be used in the electricity production, industry and household sector (MANRE, 2010), making the energy sector less sensitive to increasing energy demand patterns.

[1] There is a minor contribution of coal and lignite (1%) to the primary energy consumption. The major consumer of this type of energy resource is industry and in particular cement production.
[2] Reflecting 10% energy savings comparing to the energy consumption of the reference year.

Based on the measures taken so far and those under way, the adaptive capacity of the cooling/heating energy demand was ranked as High.

Conclusions

Energy requirements are linked to climate conditions and the relationship of energy demand and temperature is not linear. The variability of ambient air temperature is closely linked to energy consumption, whose maximum values correlate with the extreme values of air temperature (maximum or minimum). As regards impacts of climate change on energy consumption, the investigation shows that for the 'cold' period of the year (November to April), a decreasing trend in energy consumption is evident as warmer conditions dominate by 2050. In addition Heating Degree Day testifies that energy demand is projected to decrease during spring and winter in the near future in Cyprus, where the maximum declines are anticipated in mountain areas. On the other hand, for the 'warm' period of the year (May-October), an increasing trend in energy consumption is evident as warmer conditions dominate by 2050. Concerning Cooling Degree Day, significant increases in energy demand for cooling are expected during summer as well as autumn in the near future. Maximum increases are anticipated mainly in inland regions as well as in southern and southeastern areas. However, given that there is potential for increasing energy supply in Cyprus in order to meet the increasing energy demand, the vulnerability towards this impact decreases.

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