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The Economic Effect of Climate Change on Electricity Use – A Case Study from Cyprus

Theodoros Zachariadis

Department of Environmental Science and Technology, Cyprus University of Technology

Panos Hadjinicolaou

Energy, Environment and Water Research Centre, The Cyprus Institute

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Executive Summary

This paper assesses additional electricity requirements and the associated costs in the Mediterranean island of Cyprus because of projected anthropogenic climate change. For this purpose an econometric model of electricity demand is used, in combination with climate projections from a state-of-the-art Global Circulation Model with a regional focus on the Eastern Mediterranean. Results indicate an increase in total power needs by the mid-21st century compared to a 'no climate change' case. Annual electricity demand is projected to rise by 5.6%, causing annual welfare losses of up to more than 100 million Euros at 2010 prices. Although additional power requirements are not very remarkable on an annual basis, climate change is expected to exacerbate the already existing imbalance between winter and summer electricity demand. This outlook indicates that a reasonable and cost-effective future energy path in regions with Mediterranean climate would involve substantial deployment of solar-powered electricity generation, a zero-carbon energy source that can meet peak load requirements without increasing the country's dependency on imported fossil fuels. Moreover, this forecast highlights the need for adaptation to climate change through substantial investments in the improvement of the energy performance of the Mediterranean building stock.

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ΠΕΡΙΛΗΨΗ

Αναλύοντας με κατάλληλες οικονομετρικές μεθόδους τη διαχρονική εξέλιξη της κατανάλωσης ενέργειας στην Κύπρο και την επίδραση παραγόντων όπως η οικονομική δραστηριότητα, τα εισοδήματα των νοικοκυριών, οι τιμές των καυσίμων, η τεχνολογική πρόοδος και οι κλιματικές συνθήκες, εξετάστηκε η πιθανή εξέλιξη της κατανάλωσης ηλεκτρισμού στην Κύπρο έως το 2050, σε συνάρτηση με την εξέλιξη των μακροοικονομικών μεγεθών, των τιμών του πετρελαίου και των καιρικών συνθηκών. Σύμφωνα με τα αποτελέσματα, εφόσον συνεχιστούν οι τάσεις που παρατηρήθηκαν κατά τις τελευταίες δεκαετίες και ακόμα και αν επέλθουν σημαντικές αλλαγές στις διαθέσιμες τεχνολογίες, η χρήση ηλεκτρισμού αναμένεται να υπερδιπλασιαστεί κατά τα επόμενα 35–40 χρόνια, με αυξανόμενη συμμετοχή των οικιακών καταναλωτών και του τριτογενούς τομέα της οικονομίας. Με βάση τα παραπάνω, διενεργήθηκε πρόβλεψη υποθέτοντας σταδιακή μεταβολή των καιρικών συνθηκών λόγω της κλιματικής αλλαγής. Για τον σκοπό αυτό, αξιοποιήθηκαν τα αποτελέσματα από λεπτομερή κλιματικά μοντέλα για την Ανατολική Μεσόγειο, σύμφωνα με τα οποία η μέση θερμοκρασία στην περιοχή της Κύπρου αναμένεται να αυξηθεί περί τον 1°C τη χειμερινή περίοδο και κατά 2°C περίπου τους καλοκαιρινούς μήνες έως το 2050. Εφαρμόζοντας το μοντέλο μας, υπολογίσαμε ότι η κατανάλωση ηλεκτρισμού στην Κύπρο θα αυξηθεί μέχρι το 2050 κατά 5,6% περίπου σε ετήσια βάση λόγω κλιματικής αλλαγής.

Οι αυξημένες ανάγκες για ηλεκτρισμό αναμένεται να οδηγήσουν σε άμεσο κόστος 35-40 εκ. Ευρώ το 2020 και άνω των 100 εκ. Ευρώ το 2050, ενώ η παρούσα αξία του συνολικού κόστους για την περίοδο 2011-2050 υπολογίζεται να ξεπεράσει τα 550 εκ. Ευρώ (σε σταθερές τιμές 2010). Η κλιματική αλλαγή προβλέπεται ότι θα επιτείνει την ασυμμετρία στη ζήτηση ηλεκτρισμού μεταξύ της θερινής και της χειμερινής περιόδου. Για τον λόγο αυτό, η μελέτη μας καταλήγει με προτάσεις πολιτικής για την αξιοποίηση της ηλιακής ενέργειας – που μπορεί να ανταποκριθεί στην υψηλή ζήτηση ηλεκτρισμού της θερινής περιόδου – και τη βελτίωση της ενεργειακής απόδοσης των κτηρίων της Κύπρου, κάτι που θα οδηγήσει σε μειωμένη εξάρτηση από τις κλιματικές συνθήκες.

1. INTRODUCTION

According to the current scientific consensus, warming of the global climate system seems to be unambiguous, and is most likely due to anthropogenic emissions of greenhouse gases (Hegerl et al. 2007). Energy supply and demand are expected to be among the sectors to be seriously affected by climate change; virtually all energy sources, from hydropower to solar power, and all energy infrastructure, from thermal power plants to electricity transmission lines, may experience various disruptions because of climate change induced events (Schaeffer et al. 2012). In the case of Europe, some positive effects are projected for hydropower production in northern Europe due to higher rainfall levels and glacier melt. Conversely, hydropower production in southern Europe is projected to decrease by 25% or more by 2050 and up to 50% by the 2070s, as the hydropower sector highly depends on water. Furthermore, extreme heat waves can pose a serious threat to uninterrupted electricity supply, mainly because cooling air may be too warm and cooling water used in power generation may be both scarce and too warm. Extreme weather events, flooding and storm surges could damage infrastructure in vulnerable areas causing power outages. On the demand side, energy requirements for heating in winter will decrease in higher latitudes while demand for summer cooling will rise in South Europe (Behrens et al. 2010). In general, the main impact of climate change on energy demand is expected in buildings, hence the growing number of studies in recent years (see e.g. Xu et al. (2012) for an extensive review).

A limited number of studies exploring climate change impacts on energy use have been performed for Mediterranean countries and have found climate change to considerably affect summer electricity demand (Giannakopoulos et al. 2009, Mirasgedis et al. 2007, Zachariadis 2010a). The Eastern Mediterranean is not the only world region with semi-arid climate conditions and high dependence on summer electricity use: areas such as California and Australia display similar characteristics and similar vulnerability to climate change, hence there has been a number of earlier analyses that have focused on these regions (see e.g. Franco and Sanstad (2008) and Mendelsohn (2003) for California, and Ahmed et al. (2012) and Howden and Crimp (2001) for Australia).

In this paper we present an assessment of climate change effects on electricity needs in Cyprus, a small island state in the Eastern Mediterranean with a population of about 800 000, which became a member of the European Union (EU) in 2004[1]. The country possessed no indigenous fossil energy resources and is therefore highly dependent on imported petroleum products. Its power system is isolated and depends mainly on fuel oil for the operation of power plants, with plans to use natural gas for some of its power generating capacity by 2016. In terms of climate change impacts, Cyprus is located in a hot spot: it already has a semi-arid climate and is located in a region that is expected to experience the most adverse climate change effects in Europe (Lelieveld et al. 2012a), with significant temperature increases and some drop in already low rainfall levels (Hadjinicolaou et al. 2011). Electricity is especially important for the country both due to its isolated national power system, which has to satisfy all demand at any time in order to avoid economically damaging power outages, and because residential and commercial buildings account for 80% of total final electricity consumption. As all space cooling appliances and 38% of space heating devices use electricity (Cystat 2011), power usage in buildings has two peaks, one in summer and one in winter months (Panayiotou et al. 2010). Therefore, changes in winter and summer temperatures due to climate change will affect the energy needs of buildings, and particularly their electricity requirements.

We use an empirical model of electricity demand in Cyprus that was developed a few years earlier through a comprehensive econometric analysis of electricity demand (Zachariadis 2006). In 2008-2009 the econometric estimates were updated by using additional recent data, which led to newly estimated elasticities. On the basis of this econometric model, Zachariadis (2010a) performed electricity projections up to 2030 under the assumption that average temperature in the Eastern Mediterranean is expected to rise by about 1°C by that year. He estimated electricity consumption in Cyprus to be 2.9% higher in 2030 than without climate change, calculated the welfare loss of additional electricity needs to reach 45 million Euros in 2030 (at constant prices of year 2007) and assessed the present value of costs for the entire period 2008-2030 to exceed 200 million Euros'2007.

[1] The information provided here refers only to the area controlled by the government of the Republic of Cyprus.

Apart from using up-to-date forecasts of macroeconomic and oil price variables, our paper expands and improves that earlier study in two important aspects. Firstly we extend the forecasts up to the mid-21st century, which is more meaningful because climate change is expected to be more pronounced by that time rather than in the first decades of the century. In doing so, we are faced with issues regarding the appropriate use of econometrically estimated model parameters for a long term energy forecast that extends to a period when many structural changes in economic activities, technology and energy use should be expected. Secondly we base our forecast on temperature projections from detailed regional climate model (RCM) simulations that have been carried out with the aid of Global Circulation Models (GCM), and are the most up-to-date state-of-the-art climate forecasts for the Eastern Mediterranean.

After presenting briefly the econometric model in Section 2, we report in Section 3 the results of the climate simulations underlying our subsequent electricity forecasts. We then present forecasts of electricity consumption by main economic sector up to the year 2050, for scenarios with and without climate change; this enables us to assess the potential climate induced change in electricity demand as well as the economic losses associated with the additional power needs in the country. Section 4 reports on the assumptions and results of the 'no climate change' case while Section 5 describes the corresponding results of the climate change scenarios. We discuss the policy implications as well as the advantages and shortcomings of our top-down economic approach in the concluding section.

2. THE ELECTRICITY DEMAND MODEL

Obtaining time series of annual sectoral electricity consumption data we were able to conduct econometric estimations with single-equation autoregressive distributed lag (ARDL) models. A similar approach is followed by international organisations and energy planning authorities worldwide, where forecasts of population, economic growth, fuel prices and other parameters are exogenous to the model. ARDL models pose several advantages over other time series econometric methods such as Vector Error Correction and cointegration techniques because they do not require testing for unit roots in variables, which is important because unit root tests in small samples often have inadequate statistical properties; this is particularly relevant in the case of Cypriot energy data, with sample sizes of 40-50. Moreover, as Clements and Madlener (1999) point out, the ARDL approach places more ‘structure’ on the issue of energy consumption than the purely theoretical cointegration approaches.

Using all variables in levels, the ARDL equation is the following:

$$e_t = \gamma_0 + \sum_{i=1}^{m} \gamma_{1i} e_{t-i} + \sum_{j=0}^{n} \gamma_{2j} y_{t-j} + \sum_{k=0}^{p} \gamma_{3k} p_{t-k} + \sum_{l=0}^{q} \gamma_{4l} tdd_{t-l} + \xi_t \quad (1)$$

where *e*, *y* and *p* denote the natural logarithm of the corresponding electricity, income and price variable respectively. *tdd* is the logarithm of total (heating + cooling) degree-days[2]. Index *t* denotes time in years, and *i,j,k,l* denote the lags of each one of the exogenous regressors. Finally, the error term ξ_t is assumed to be independently and normally distributed with zero mean and constant variance. As the variables are expressed in logarithms, the econometrically estimated coefficients γ_{1i}, γ_{2j} etc. express elasticities. Zachariadis (2010a) provides details on the data that were used for these estimations. The models passed the standard statistical diagnostic tests and the estimated parameters γ were reasonable in both their sign and their magnitude. The degree-day variable is statistically significant in both sectors dominated by building energy needs (residential and commercial sector) and turned out to be insignificant in the industrial and agricultural sectors. Separating the degree-day variable in two variables, one for cooling and one for heating degree-days (relevant for summer and winter energy needs respectively), was not meaningful as the coefficients of both variables were of the same magnitude, hence we used the total degree-day variable shown in Eq. (1).

After conducting some initial estimations with the whole sample (period 1960–2007) and confirming the good statistical properties of these regressions, we then examined whether the estimated coefficients have changed significantly over the years. We thus performed rolling regressions for 20-year periods (1961–1980,

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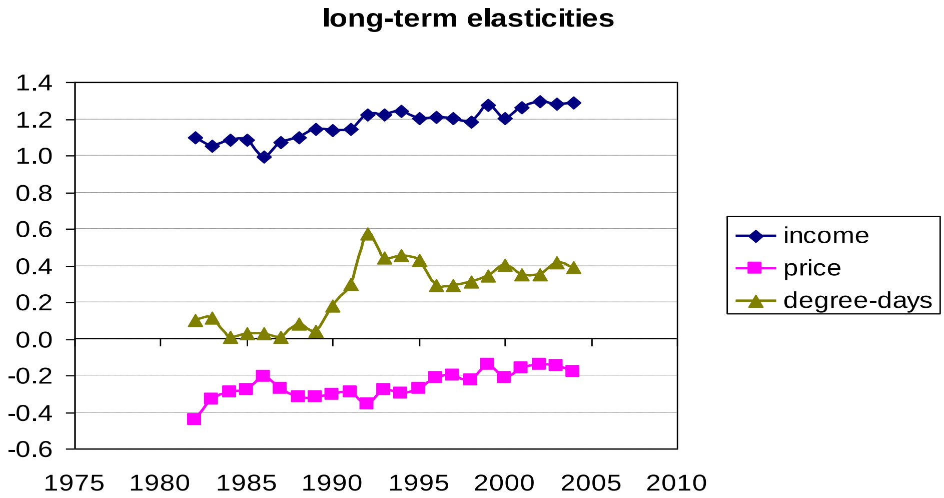
[2] Heating (cooling) degree days are meant to measure the severity and duration of cold (hot) weather: for example, the colder the weather in a given month or year the higher the heating degree day value. One degree-day expresses the need for heating (or cooling) during a day caused by an average daily temperature that is one degree lower (or higher) than a reference temperature. See e.g. the exact definition of Ahmed et al. (2012). We used 18ºC and 22ºC as reference temperatures for heating and cooling degree-days respectively (see also Giannakopoulos et al. (2009)).

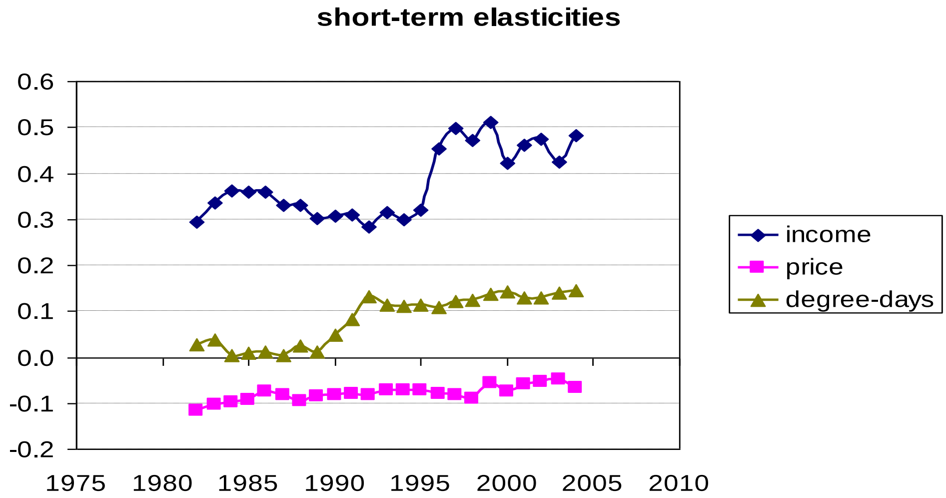
1962–1981, … 1988–2007) and found that the coefficients of Eq. (1) have remained stable in the industrial sector but have changed consistently over these decades in the residential and commercial sector: as shown in Figures 1 and 2, price elasticities of electricity use have decreased in absolute terms whereas income and weather elasticities have risen. This effect should be attributed to the fact that – because of technology and falling costs – electricity-consuming appliances have become so widespread in households, offices, shops and hotels that prices affect very little the amount of electricity people use; moreover, the market penetration of air conditioning appliances have made electricity use in Cyprus more dependent on weather conditions: as long as people have such devices available they will make use of them when weather becomes hot. Chong (2012) found similar evidence through detailed econometric estimation of building energy use in Southern California, another region with Mediterranean climate: in more recent years, and despite the gradual implementation of stricter energy efficiency requirements, newer buildings turned out to consume more electricity in hot weather conditions.

We therefore considered more appropriate to apply the elasticities estimated for the most recent 20-year period in our electricity forecasts, because they can be considered to better reflect today's conditions in Cyprus. We also used, however, a second set of elasticities with gradually declining income elasticities, for reasons that we explain in Section 3.

Figure 1: Results of rolling 20-year regressions: Temporal evolution of short and long term elasticities of electricity demand in the residential sector.

Figure 2: Results of rolling 20-year regressions: Temporal evolution of short and long term elasticities of electricity demand in the commercial sector.





3. CLIMATE PROJECTIONS FOR CYPRUS

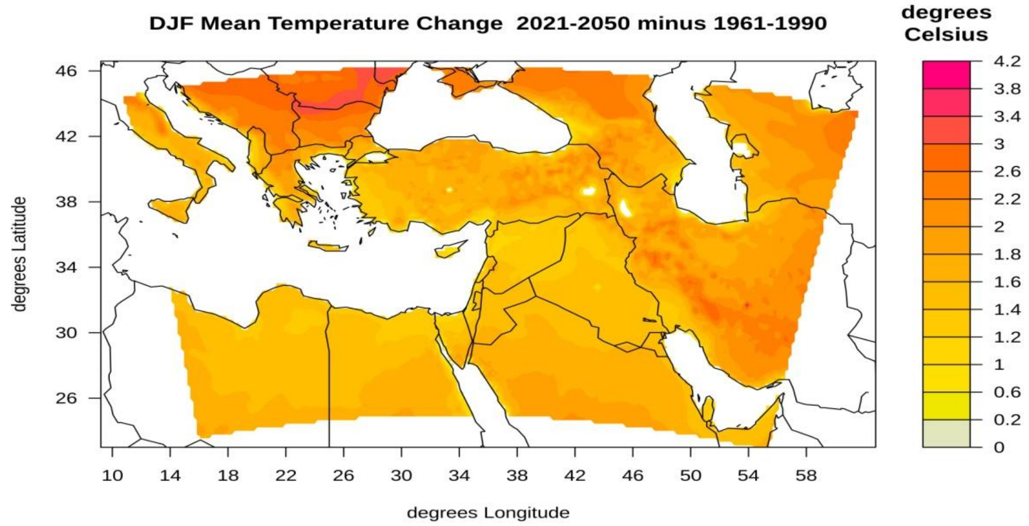
3.1 Model simulation

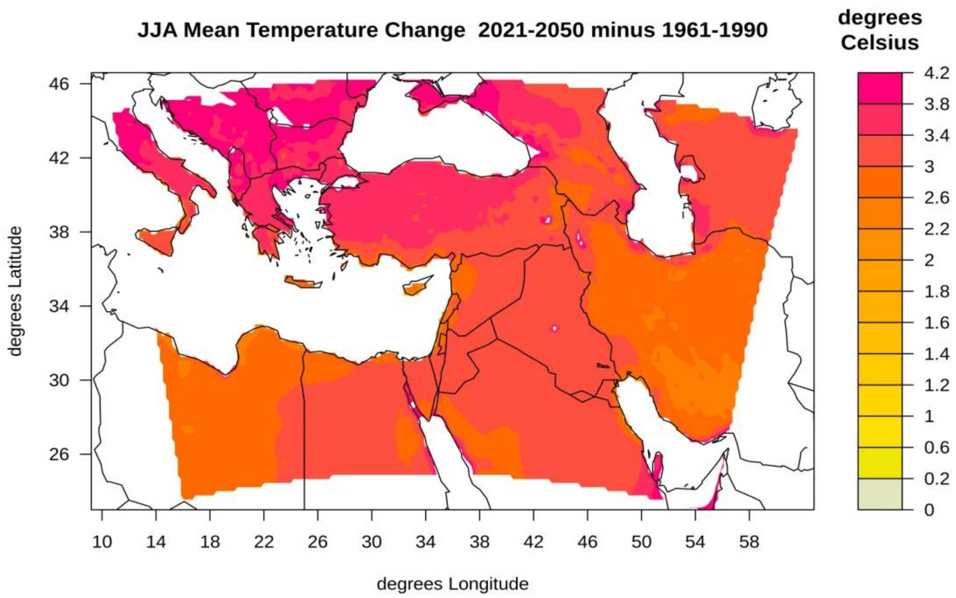
To assess the future climate evolution in the region of Cyprus the PRECIS (Providing Regional Climates for Impact Studies) regional climate model was used, which is based on the UK Meteorological Office Hadley Centre's HadRM3P Regional Climate Model (Jones et al. 2004). The RCM was forced by lateral boundary conditions taken from the simulation of the parent GCM HadCM3 (Collins et al. 2005), which is driven by global greenhouse gas emission forecasts of the A1B emissions scenario of the United Nations Intergovernmental Panel on Climate Change (Pachauri and Reisinger 2007). PRECIS was run from year 1950 to year 2099 over the Eastern Mediterranean and Middle East in a horizontal resolution of 25 km x 25 km. Lelieveld et al. (2012a) demonstrated that this simulation was able to capture the mean climatic conditions as well as the increasing temperature tendency of the 20th century in the region.

Considering the whole simulation domain, it is evident from Figure 3 that the increase in mean temperature, by 2021-2050, will range from 1-4°C. This projected warming is 2-3 times larger than what the region has experienced in the second half of the 20th century (Tanarhte et al. 2012), and for the summer months it appears to be more pronounced at latitudes greater than 38°N (more than 3°C in the Balkans, Asia Minor and Caucasus) and weaker at places in the southern part of the domain (not exceeding 2.5°C in Libya and Iran). For winter months the warming is more homogeneous spatially. This geographically asymmetric summer warming can be explained by the projected drying in the region and through the interaction between the atmosphere and soil-moisture in the areas which are sensitive to this feedback (Zittis et al. 2012).

Figure 4 presents the PRECIS results for the coordinates of Nicosia (the capital city of Cyprus), expressed as anomalies from the long-term mean of annual time-series of maximum temperature, from 1950 to 2099. In the same plot are shown the respective observations from 1971 to 2009. The lowess fits, conducted through locally-weighted polynomial regression according to Cleveland (1981), smooth inter-annual variability and reveal the long-term tendency. The small increase in observed temperature after 1990 is partly captured by the model adding confidence to the projectio[3]. PRECIS projects an almost linear warming throughout the 21st century to +4°C with large inter-annual variability.

Figure 3: Projected change in mean temperatures in winter (top) and summer (bottom) in the Eastern Mediterranean up to the mid-21st century.

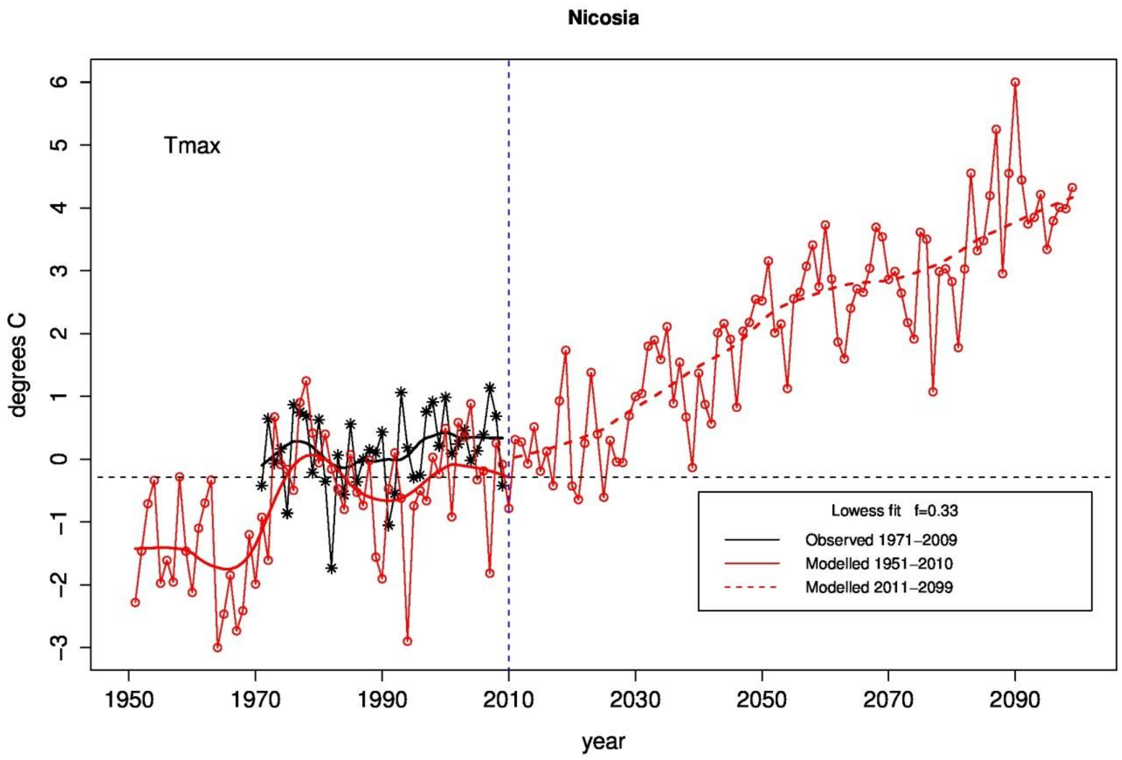




[3] For a more detailed validation of this simulation see Lelieveld et al. (2012a).

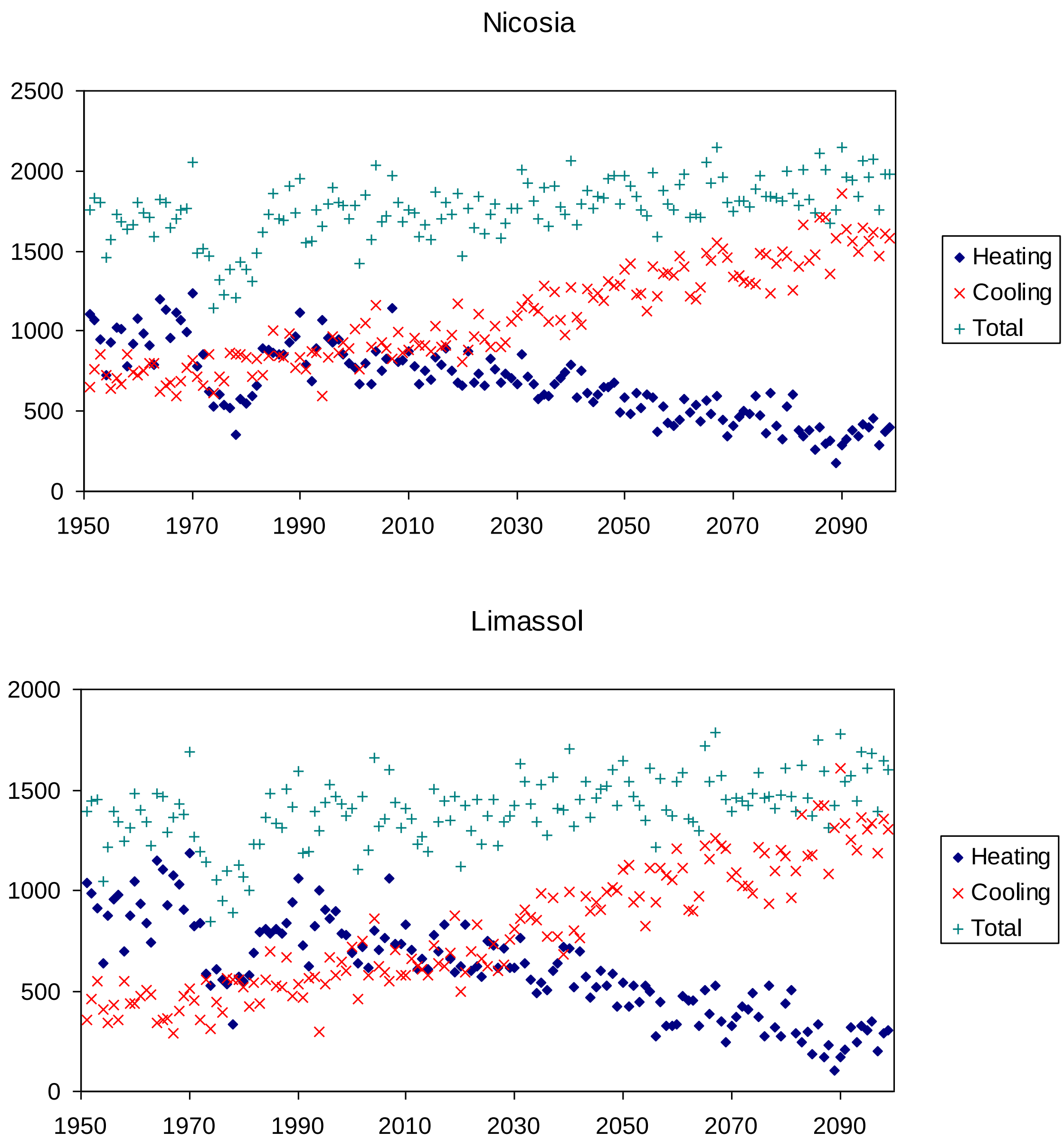
On a seasonal basis, summer warming is projected to be 1°C larger than winter by mid-century (Hadjinicolaou et al. 2011). Besides this mean warming, Cyprus may also experience intense heat extremes. Lelieveld et al. (2012b) analysed the PRECIS output for Nicosia (among other capitals in the region) and found that heat wave duration could increase by 7-10 times by 2099, exceeding 4 months per year, and that the coolest summers at the end of the century will be warmer that the hottest ones in the recent past.

Figure 4: Annual time-series of maximum temperature (anomalies from the mean of years 1971-2009) for Nicosia from the PRECIS model (red) and observations (black). The lines represent Lowess smoothing (see figure legend box).



As a result of these climatic projections, Figure 5 shows the evolution of heating, cooling and total degree-days for the two major cities of Cyprus in the period 1950-2099. Our projections clearly indicate a decline in heating degree-days because of warmer winter months, and an increase in cooling degree-days because of a hotter summer period. In total the number of degree-days rises modestly, by about 10% as will be explained in the next Section.

Figure 5: Evolution of heating, cooling and total degree-days in the cities of Nicosia and Limassol for the period 1950-2099, according to climate projections.



Notes: (a) Reference temperatures are 18°C for heating and 22°C for cooling degree-days. The PRECIS data have been corrected with the bias from the observed 1980-2000 climatology – see Figure 4., (b) Note the different scale of the Y-axis, reflecting the milder climate of Limassol with warmer winters and cooler summers.

3.2. Use of climate model results for electricity forecasts

As mentioned in Section 2, the electricity model of Eq. (1) uses total annual degree-days as its climate variable. In order to compute the additional electricity needs in the coming decades as a result of climate change, it is necessary to perform two electricity forecasts: a reference case that assumes no climate change and a case that is consistent with the climate change simulations presented in Section 3.1. The difference between the two projections provides a measure for additional power usage under climate change conditions. If two distinct sets of climate simulations were available, one without and one with climate change, one could compute annual degree-days for every future year according to each scenario and then carry out annual electricity forecasts according to Eq. (1) by scenario. However, this is feasible only in the latter case (with climate change); for the former case this is not possible because climate modellers do not include a 'no climate change' scenario in their simulations as this is considered implausible in view of increasing atmospheric greenhouse gas concentrations and the changes in the earth's energy balance that these entail.

To overcome this obstacle and conduct the desired comparison, we had to rely on a simplified simulation. We calculated the projected annual degree-days from the climate predictions of Section 3.1. We then computed the forecast degree-days of year 2050 as the average of annual degree-days of the 30-year period 2036-2065. This is a standard procedure to calculate climate variables because random year-to-year climate fluctuations may lead to an inappropriate value of that variable for one specific year. Similarly we obtained the corresponding average degree-day value from meteorological observations of the recent past (years 1978-2007) that are consistent with our climate model predictions. We assumed that the latter figure would remain constant over the next fifty years for our 'no climate change' scenario of Section 4. Then for the 'climate change' case we assumed that annual degree-days will increase linearly from the 1978-2007 average in year 2010 to the 2036-2065 average in year 2050 (a 10.0% increase according to the climate model[4]), and performed the forecasts of Section 5.

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[4] This is based on figures from the city of Limassol. Average for 1978-2007: 1331 degree-days (763 heating and 568 cooling); average for 2036-2065: 1465 degree-days (497 heating and 968 cooling). A similar picture emerges for the city of Nicosia, with total degree-days equal to 1685 for 1978-2007 and 1831 for 2035-2065.

4. FORECASTS OF ELECTRICITY USE IN THE REFERENCE CASE

Eq. (1) can be used for forecasts of future electricity consumption by sector. The dependent variable (electricity demand) will be determined from the econometrically estimated coefficients γ and the future evolution of the exogenous income, price and weather variables. Therefore, it is necessary first to assume the evolution of the exogenous variables up to 2050.

For some macroeconomic variables (GDP, private consumption) official short-term forecasts of the Cypriot Ministry of Finance and international organisations were used. As for the evolution in the longer term, it was assumed that economic growth will continue albeit at gradually lower rates; this is line with official demographic projections for Cyprus, which foresee that total population will start declining around 2030, so that moderate total GDP growth combined with a decreasing population will lead to a quite stable growth rate in per capita GDP of the order of 1.9% per year. Table 1 shows these assumptions. As regards the contribution of each economic sector to total GDP, it was assumed that the share of industry and agriculture will slightly fall in the future, whereas the share of the tertiary sector will increase further. The evolution of sectoral GDP shares is also illustrated in Table 1.

Table 1: Forecast of real GDP, private consumption and sectoral GDP shares in Cyprus up to 2050.

	Actual values in 2010	*Forecast of real growth rates (average over each decade)*			
	(mio Euros)	*2010-2020*	*2020-2030*	*2030-2040*	*2040-2050*
GDP	17 465	2.1%	2.3%	2.0%	1.6%
Private consumption	11 928	1.1%	2.1%	2.0%	1.6%
Sectoral GDP shares	*Actual in 2010*	*2020*	*2030*	*2040*	*2050*
Agriculture	2.0%	1.8%	1.6%	1.5%	1.4%
Industry	9.6%	9.2%	8.8%	8.5%	8.3%
Construction	7.6%	8.0%	8.5%	8.8%	9.0%
Services	80.8%	80.9%	81.1%	81.2%	81.3%

Source: Authors' assumptions based on national accounts, forecast from the Ministry of Finance of Cyprus, short-term economic forecasts of the European Commission for Cyprus (November 2011) and projections from IMF World Economic Outlook Database (September 2011).

As for the projection of end-user electricity prices, they almost entirely depend on international oil prices as the major part of the power generation sector in Cyprus is based on fuel oil burning plants, with a small fraction of power coming from diesel internal combustion engines and a very small part by wind farms, solar photovoltaic panels and biogas fired turbines. Retail electricity prices are linked with fuel oil import costs. Therefore, we made use of official crude oil forecasts of the US Energy Information Administration (2011) as of September 2011, applied a previously estimated equation that links annual fuel oil import costs with annual crude oil prices (Zachariadis 2010a), and applied an official relationship linking fuel oil prices with retail electricity prices to arrive at forecasts of the latter variable. Table 2 shows these forecasts.

Table 2: Forecasts of international oil prices and retail electricity prices in Cyprus

	Actual	*Forecast*			
	2010	*2020*	*2030*	*2040*	*2050*
Crude oil price (US$'2009 / barrel)[a]	78.0	108.1	123.2	126.8	130.5
Electricity price (Eurocents'2010 / kWh)					
Domestic consumers	16.2	17.5	18.1	18.3	18.4
Industry	15.0	16.3	16.9	17.1	17.2
Agriculture	15.4	16.8	17.4	17.5	17.7
Commercial consumers	16.8	18.2	18.8	18.9	19.0

[a] Source: EIA (2011) for forecasts up to 2035 and authors' extrapolations for 2036-2050.

Energy price forecasts are associated with large uncertainties, both because of uncertainties in international energy markets and because of unknown developments at national level. In Cyprus, for example, natural gas is expected to enter the market by 2015/2016, and the share of renewable electricity is expected to rise in the coming years. It is not clear, however, to what extent such changes may affect retail prices electricity; moreover, as price elasticities are quite low in absolute terms, even large price fluctuations will most probably have a small influence on electricity consumption. Therefore, and as this study aimed to focus at the effect of rising temperatures on energy use, it was considered appropriate to proceed with one price scenario.

Finally, as regards the total degree-days variable, in the reference case scenario it was assumed that future climate conditions will remain the same with the average of the last decade. Note that the degree-days variable used in the econometric estimations is the average of total annual degree-days for the two largest cities – Nicosia and Limassol – where around two thirds of the country's whole population lives.

Table 3 presents the forecasts of electricity demand according to these assumptions. If past trends continue, electricity use in Cyprus is projected to increase by 70% in 2030 compared to 2010, and by another 65% in 2050 compared to 2030. Electricity consumption per capita is expected to rise 2.5 times and per unit of GDP to increase by 27% in 2050 compared to 2010. Residential and commercial sectors, responsible for 80% of consumption in 2010, will further increase their dominance, accounting for 85% of the electricity needs in 2050. Interestingly, although this growth seems to be strong, it is much less pronounced than the corresponding increase that was projected by Zachariadis (2010a), based on macroeconomic and energy price forecasts of the year 2008, before the global financial crisis. According to that study, total electricity demand was projected to exceed 12 000 GWh in 2030 – whereas in our forecast electricity use reaches the same level only in year 2045. One reason for our lower estimates is that international oil prices are now projected to increase further in the coming decades, whereas older forecasts relied on markedly lower oil price assumptions; higher oil prices lead to higher retail electricity prices and hence to lower electricity consumption. The second and most important reason is the considerably lower GDP projection in this study: whereas Zachariadis (2010a) used exogenous GDP forecasts for the year 2030 of around 28 billion Euros at 2000 prices (37 billion Euros at 2010 prices), our current GDP forecast is about 27 billion Euros'2010. The economic stagnation of years 2009-2012 in Cyprus is projected to leave the economy at a lower overall growth path.

Despite lower growth, the rising trend in per capita electricity demand is still substantial. As shown by Zachariadis (2006) through an international comparison, future levels of electricity use in Cyprus are comparable to those of high per capita power consuming countries such as Australia, the United States or Sweden. Is this evolution plausible? On the one hand electricity use has grown unabated during the last decades, without any signs of saturation. On the other hand, it may be reasonable to expect a break in past trends. Many structural changes are expected in the time horizon of our projections, with a general tendency towards more energy efficient appliances, processes and buildings. Whereas national energy efficiency standards did not exist in Cyprus until very recently, current legislation in the European Union foresees a serious improvement in the energy performance of new buildings starting around 2020. Besides it is reasonable to expect some saturation in the use of electricity, i.e. the growth rate of energy needs with income should be expected to gradually decrease, because electrification has proceeded very significantly in the country. For these reasons we carried out an alternative forecast, assuming that income elasticities in all economic sectors will gradually decline from year 2015 onwards. More specifically, we assumed the short-term income elasticities of domestic, industrial and residential consumers to remain constant up to year 2020 and then to fall gradually from 0.65, 0.12 and 0.31 to 0.63, 0.11 and 0.30 in year 2050 respectively. From the autoregressive specification of Eq. (1) it follows that the corresponding long-term elasticities in the three sectors will decline from 1.58, 1.20 and 1.14 in 2020 to 1.53, 1.15 and 1.10 in 2050 respectively.

Table 3: Forecast of electricity consumption in Cyprus up to 2050, by economic sector.

	2010	2020	2030	2040	2050
Real GDP (million €'2010)	17 465	21 408	26 967	32 807	38 584
Population (000)	839.8	909.9	934.3	930.3	906.0
Electricity consumption (GWh)					
Domestic consumers	1737	2046	2982	4283	5739
Industry	816	1133	1348	1554	1761
Agriculture	153	174	206	255	299
Commercial consumers	2076	2703	3585	4582	5607
Total	4782	6055	8121	10674	13406
Electricity use per capita (kWh)	5694	6655	8693	11473	14798
Electricity use per unit of GDP (kWh per thousand €'2010)	273.8	282.8	301.1	325.3	347.5

Notes: Numbers for 2010 are actual data coming from national economic, demographic and energy statistics of the Republic of Cyprus.

Decreasing income elasticities indicate that a rise in GDP or private consumption will gradually have a less strong effect on electricity needs, thus reflecting potential saturation effects or impacts from energy efficiency regulations as explained above. We chose not to change the estimated values of price and weather elasticities throughout the forecast period because, in contrast to income elasticities, we believe it is highly uncertain how the response of electricity consumers to prices or the weather may change in the future.

Although the assumed change in elasticity values is small, due to the recursive model specification the effect on final electricity demand in the long term is substantial as is evident from Table 4: total power needs in year 2050 are about two thirds of those in the projections of Table 3. Therefore, this alternative forecast can be regarded as a low-end projection of the evolution of electricity needs in Cyprus up to the mid-21st century.

Table 4: Forecast of electricity consumption in Cyprus up to 2050, assuming decreasing income elasticities after 2020.

	2010	2020	2030	2040	2050
Electricity consumption (GWh)					
Domestic consumers	1737	2046	2575	3122	3539
Industry	816	1133	1299	1400	1465
Agriculture	153	174	206	255	299
Commercial consumers	2076	2703	3273	3691	3968
Total	4782	6055	7353	8467	9271
Electricity use per capita (kWh)	5694	6655	7871	9101	10233
Electricity use per unit of GDP (kWh per thousand €'2010)	273.8	282.8	272.7	258.1	240.3

Apart from comparing the projections of Tables 3 and 4 with those of our earlier studies, it is particularly useful to compare them with results of official forecasts. We use two recent projections for this purpose, one from official national authorities and one from the European Commission, the European Union's executive body. The official forecasts of national energy authorities reach up to the year 2021 and project power generation in that year to lie between 6615 and 7870 GWh[5]. Since transmission and distribution losses and energy branch consumption consistently account for about 9% of total power generation in Cyprus according to official data of recent years, the official projection corresponds to a forecast of final electricity demand in the range of 5954-7083 GWh for the year 2021. Our two forecasts for the same year (not shown in Tables 3 and 4) are 6211 and 6235 GWh and hence lie within the range of the official forecasts.

In its recent energy analyses, the European Commission (2012) projected in its reference scenario that final electricity demand in Cyprus will reach 608 thousand tons of oil equivalent (ktoe), or 7071 GWh, in the year 2030. Although this figure is lower than our low-end forecasts of Table 4, it can be explained by the fact that the Commission's estimates assume a higher level of electricity use already in 2010 – which was a forecast year in that study. The growth in total electricity consumption in the Commission's study is 65% in 2030 compared to 2010, which lies within the range of growth rates of our forecasts (54% in the low case of Table 4 and 70% in the high case of Table 3).

5. ELECTRICITY CONSUMPTION UNDER CLIMATE CHANGE

We now turn to the calculations of a climate change scenario, in line with the results of the simulations shown in Section 3. Table 5 presents the forecasts according to both high-end and low-end cases. Compared to the 'no climate change' scenarios of Tables 3 and 4, total electricity needs in 2050 increase by 5.6%. On a sectoral basis, whereas industrial and agricultural consumption do not change because degree-days were not statistically significant in the corresponding models of Eq. (1), domestic and commercial electricity consumption rise by 8.8% and 4.9% respectively. This indicates that increased temperatures in the future will affect residential buildings most. Note that the effect on total power needs does not seem to be very strong despite the considerable temperature changes up to the mid-21st century because, as illustrated in Figure 5, increased electricity requirements for additional space cooling in summer will partly be counterbalanced

[5] See webpage of the Transmission System Operator of Cyprus: http://www.dsm.org.cy

by reduced needs for electric space heating in winter. According to the econometric estimations shown in Section 2, electricity consumption in our model is equally responsive to increased temperatures both in summer and winter; hence the net effect is relatively modest on an annual basis.

In the absence of adequate seasonal data for Cyprus for all energy, macroeconomic and price variables used by our electricity model, it is not possible to calculate explicitly the seasonal effect of climate change on electricity requirements. However, it is clear that the effect during summer months will be much more pronounced. Taking into account that long-term elasticities of electricity demand with respect to degree-days range between 0.4 and 0.8 according to Figure 1, and that cooling degree-days for Nicosia and Limassol are expected to increase by 55% in 2050 according to Figure 5, it is reasonable to expect that summertime power demand will grow by 30%-35% due to climate change – on top of the forecast increase in electricity consumption according to the reference scenarios of Tables 1 and 2. Such a development calls for additional power generating capacity that should be available during summer months, which will be of limited use in winter time due to the projected decline in electricity needs during the heating season.

Table 6 presents an assessment of the economic losses associated with the increased power needs under climate change. Residential and commercial consumers will incur additional electricity expenditures in order to achieve the same thermal comfort as in the reference case without climate change. All else being equal, these additional costs will represent welfare losses because consumers will have to reduce other expenditures which they would otherwise prefer. Assuming that electricity prices will remain as in the reference scenario and that electricity is a non-substitutable commodity[6], total economic losses are estimated to start at about 13 million Euros (at constant prices of year 2010) 2020 and reach 95-141 million Euros in the year 2050. Over the entire 40-year period up

[6] We assume that producer surplus of the utilities supplying electricity will not change due to this increase in power needs because utilities are unlikely to be able to charge high prices for peak electricity needs in a small quasi-monopolistic power market as that of Cyprus. Moreover we may overestimate welfare losses because a part of electricity can be substituted by other energy forms or other activities, but on the other hand we may underestimate these losses because we do not account for additional demand for commodities that are complements to electricity. Overall, these calculations seem to be a reasonable approximation of reality.

to 2050, the net present value of additional costs is estimated to range between 555 M€'2010 in the low-end forecast and 679 M€'2010 in our high-end projections. Considering that the GDP of Cyprus was around 17 billion Euros in 2010, it is evident that these costs, although relatively low, are not negligible for such a country and call for climate adaptation policies that could keep economic losses at low levels. It has to be stressed that this calculation does not include eventual costs because of the under-utilisation of power generating capacity in winter months as explained in the previous paragraph.

Table 5: Electricity consumption in Cyprus in the climate change scenario.

	2010	2020	2030	2040	2050
(a) High-end forecast with constant income elasticities					
Electricity consumption (GWh)					
Domestic consumers	1737	2090	3112	4557	6218
Industry	816	1133	1348	1554	1761
Agriculture	153	174	206	255	299
Commercial consumers	2076	2730	3668	4747	5880
Total	4782	6126	8335	11113	14158
(b) Low-end forecast with declining income elasticities post-2020					
Electricity consumption (GWh)					
Domestic consumers	1737	2090	2690	3330	3850
Industry	816	1133	1299	1400	1465
Agriculture	153	174	206	255	299
Commercial consumers	2076	2730	3349	3825	4164
Total	4782	6126	7545	8809	9778

Table 6: Economic losses because of additional electricity needs due to climate change.

(million €'2010)	2020	2030	2040	2050
(a) High-end forecast with constant income elasticities				
Domestic consumers	7.7	23.8	50.2	88.6
Commercial consumers	4.9	15.6	31.3	52.2
Total	12.6	39.4	81.6	140.7
Present value of total cost for period 2011-2050:				678.9
(b) Low-end forecast with declining income elasticities post-2020				
Domestic consumers	7.7	21.0	38.2	57.6
Commercial consumers	4.9	14.3	25.4	37.3
Total	12.6	35.3	63.6	94.9
Present value of total cost for period 2011-2050:				555.3

Notes: Present value of costs was calculated with a real social discount rate of 4%.

6. DISCUSSION AND CONCLUSIONS

In this paper we assessed additional electricity requirements (and the associated costs) in the Mediterranean island of Cyprus because of projected anthropogenic climate change. For this purpose we used an econometric model of national electricity demand, in combination with detailed climate projections from a state-of-the-art Global Circulation Model with a regional focus on the Eastern Mediterranean. Our results indicate an increase in total power needs by the mid-21st century induced by climate change: total annual electricity demand is projected to rise by 5.6%, causing annual welfare losses of up to more than 100 million Euros (at 2010 prices) because of increased energy expenditures of households and firms. Although total additional power requirements are not very remarkable on an annual basis, climate change is expected to exacerbate the already existing imbalance between (low) winter and (high) summer electricity demand. Without electrical interconnections with any other country, Cyprus may have to address this imbalance with investments in peak load generating capacity that will be under-utilised during most of the year – thus leading to additional costs.

As shown in Figure 4, changing climate is expected to further intensify these problems in the second half of the 21st century – which we have not studied in this paper as energy forecasts for such a long term would be associated with much larger uncertainty. This general picture can provide valuable insights to policy makers trying to address the potential costs of climate change to the energy system and the economy of countries with a Mediterranean climate. In particular, this outlook indicates that a reasonable (and probably cost-effective) future energy path would involve substantial deployment of solar-powered electricity generation, a zero-carbon energy source that can meet peak load requirements during summer months without increasing the country's dependency on imported fossil fuels.

A second lesson for governmental policy is related to the well documented needs for adaptation to climate change. In a region like the Mediterranean, which is expected to experience adverse climate change impacts, additional energy needs in buildings can be alleviated to some extent by increasing their energy efficiency – a field in which Mediterranean countries have not been very successful so far. Proactive implementation of EU policy initiatives such as the requirements for nearly zero energy buildings (European Commission 2010), as well as provision of economic incentives for refurbishment of older buildings, can reduce energy expenditures, mitigate the growth in greenhouse gas emissions and contribute to adaptation at the same time: a more efficient building is less vulnerable to changes in ambient conditions and hence can offer thermal comfort to its occupants without high energy requirements.

Clearly, our analysis is not free of problems. The top-down economic approach we utilised here is agnostic to technical details of building energy needs such as the materials used or the efficiency of technologies applied for electricity-based heating, cooling, lighting and appliances. Besides, it is well known to engineers that cooling/heating degree-days is a rough measure of outside temperature that cannot lead to accurate estimation of energy needs (Guan 2009). A further legitimate criticism is that average degree-days cannot capture non-linear effects of climate change – for example the more frequent occurrence of extreme weather events such as heat waves as described in Section 3.1.

These are obvious limitations of our methodology. However, bottom-up engineering calculations of electricity demand, which can address such shortcomings, have other weaknesses: they often fail to predict the real-world evolution of aggregate electricity needs because they overestimate the technological potential and underestimate the persistence of behavioural patterns of energy consumers. In Cyprus, for example, engineering analyses have often underestimated the future growth rate of power requirements: analysts have cited the increased efficiency of electric appliances and the saturation of the national market for appliances and air conditioners due to the high living standards in the country, to conclude that electricity use will grow at rates much lower than the historically observed ones[7] – something that did not materialise up to now. We do not know to what extent electricity consumption will rise more modestly in the future. On the one hand, saturation may indeed be approaching in some cases – for example, 81% of all households possessed one or more air conditioning units in 2009 (Cystat 2011) – and energy efficiency obligations may lead to unprecedented savings in new buildings. On the other hand, the country is increasingly dependent on electricity-intensive desalination plants to satisfy its growing water demand (Zachariadis 2010b); and electric mobility is currently a promising option worldwide, which may materialise in Cyprus to an unknown extent. Therefore, long-term electricity forecasts are associated with large uncertainty, which good engineering knowledge of technologies cannot resolve. Similarly to the scenario-based analyses of international organisations (EIA 2011, European Commission 2012, IEA 2010) we chose to address this uncertainty by producing two forecasts, depending on assumptions about the future development of sectoral income elasticities; although it cannot explain the evolution of electricity use in detail, it is a reasonable approach that provides a range of the possible evolution in future decades.

A promising next step is to compare top-down forecasts such as those presented in this paper with detailed bottom-up surveys of the energy behaviour of the country's actual building stock and the corresponding engineering-based forecasts. In this way it might be possible to reconcile economic and engineering approaches and improve the reliability of electricity forecasts and climate change impact assessments. Current bottom-up work on this topic (Fokaides et al. 2012, Panayiotou et al. 2011), although detailed and very useful, has to be extended to non-residential buildings and needs to be complemented by forecasts of future energy use. As these extensions are not available at the time of writing, such a rigorous interdisciplinary approach has to be deferred to future research.

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[7] See e.g. the historical evolution of annual power generation forecasts conducted by the national Transmission System Operator during the last decade (available at http://www.dsm.org.cy).

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