# Discussion Paper: Impacts of Climate Change on Regional Energy Systems

## 1. Abstract

According to the findings from the ESPON applied research project on natural and technological hazards[1], certain regions in Europe are clearly more vulnerable to environmental risks derived from climate change. This vulnerability has been documented with regard to the possible impacts of storms, draughts, floods and forest fires. It is assumed that climate change will in general lead to more extreme weather conditions, putting additional pressure on the energy infrastructure in terms of production, transport and distribution. According to present evidence and modelling, energy **production** will be affected by changes in natural resources, such as hydro, wind power or biomass. The **transmission and distribution networks** may be exposed to greater natural impacts, derived from extreme weather conditions or forest fires, while, on the **demand side,** changes may be expected with regard to the heating and cooling demand of buildings and some industrial processes. This discussion paper summarizes the evidence available from research on climate change impacts on the energy sector and proposes policy options to minimize the possible risks on regional level.

## 2. Introduction

In the context of the ESPON project ReRisk "Regions at Risk of Energy Poverty", which will formulate policy recommendations with the time horizon of 2030, the impacts of climate change on the regional production and consumption of energy must be considered. However, little scientific evidence is presently available on the actual impacts of climate change

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[1] Schmidt-Thomé, Phillip, "*The Spatial Effects and Management of Natural and Technological Hazards in Europe*", ESPON Applied Research Project 1.3.1.

effects on the energy system. The possible affections have mainly been identified as a result of modelling exercises, which implies a high level of uncertainty with regard to the actual speed and extent of climate variations. The severest impacts are expected to occur in the longer-term horizon (between 2070 and 2100), but many experts, including the IPPC, warn of the "risk of non-linear climate change"[2] and that changes may be quicker than expected. It is therefore necessary that regional planners design "robust strategies"[3] to their local resources and infrastructure, as explained in the final section of this article.

## 3. Expected Climate Change Impacts on Energy Production

According to the latest analysis of climate change impacts in Europe[4], regions will be affected in different ways by the following trends:

- Global mean temperature has increased by presently 0.8 °C compared with pre-industrial times for land and oceans, and by 1.0 °C for land alone. Projections suggest further temperature increases in Europe between 1.0–5.5 °C by the end of the century. These temperature increases will intensify the danger of forest fires and lead to more area being burned, more ignitions and longer fire seasons, especially in southern and central Europe.

- Changes in precipitation show diverse spatial trends between a wet northern part (an increase of 10 to 40 % during the 20th century) and a dry southern part (a decrease of up to 20 % in some parts of southern Europe). This adds to changes to the hydrological cycle, due to the loss of snow cover and permafrost areas. European glaciers are melting rapidly: those in the Alps have lost two thirds of their volume since 1850, with loss accelerating since the 1980s, and they are projected to continue their decline. Snow cover has decreased by 1.3 % per decade during the past 40 years, with the greatest losses in spring and summer, and decreases are projected to continue. Precipitation extremes, causing the risk of flooding and draughts, are also expected to become more frequent.

- For the moment, there is no clear trend in the frequency and intensity of storms, but increased intensity of storms is considered likely. Sea-level rise has already been documented and will cause flooding, coastal erosion and the loss of flat and low-lying coastal

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[2] European Environment Agency (2008), "*Impacts of Europe's changing climate – 2008 indicator-based assessment*". EEA Report Nº 4/02008

[3] Dessai, S.; Hulme, M. (2007) "*Assessing the robustness of adaptation decisions to climate change uncertainties: A case study on water resources management in the East of England*". Published in Global Environmental Change 17(2007) 59-72

[4] European Environment Agency (2008), op. cit.

regions. It increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands.

- Biodiversity is already being affected by northward and uphill distribution shifts of many European plant species.

### 3.1. Impacts on Energy Production

Energy production is closely related to the availability of water resources, since they constitute the “fuel” for large and small hydropower stations, but are also needed to cool nuclear plants or for biocrop production. The consequences of climate change on the water flows of mountain watersheds[5] have been analysed for the Upper-Danube watershed in Central Europe. Supplies from this area are intensively used in the German, Austrian, Swiss and Italian border regions for hydropower production and the cooling of power plants. Expectations are that the annual low-flows, i.e. times of minimum availability of water in the river, will continually decrease from an average value of 650 $m^3/s$ today to 350 $m^3/s$ in the middle of the century. This will be the effect of complex changes in the Alpine environment, as described in the IPCC-A1B climate scenario. In the Pyrenees, dramatic effects are expected as a result of the alteration of snowpack, both with regard to thickness and duration[6]. Depending on the altitude, the maximum accumulated snow water equivalent may decrease by up to 78% and the period of snow cover will shorten considerably in those altitudes that can typically be found in the Pyrenees. In this case, the most affected area are the central and southern (Spanish) side of the Pyrenees, where “snow plays an important role in releasing high and regular spring river flows to the main tributaries of the Ebro River”[7], which, in turn will affect some important power stations in the region.

Diminishing inflows of water from the mountains will add to a pronounced decrease in precipitation, especially in the warm season in the Southern Mediterranean area[8]. Precipitations will not only be less frequent, but also more variable, making water management extremely difficult. The phenomenon will intensify over time, from about -7% in 2001 – 2020 to ~-28% in 2081 – 2100. The increase in variability, along with the large mean warming, is expected to produce a much more frequent occurrence of

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[5] Mauser, M. Bach, H. (2009) “*PROMET – Large scale distributed hydrological modelling to study the impact if climate change on the water flows of mountain watersheds*”. Published in Journal of Hydrology 376 (2009) 362-377

[6] López-Moreno, J.J., Goyette, S. Beniston, M. (2009), “*Impact of climate change on snowpack in the Pyrenees: Horizontal spatial variability and vertical gradients*”. Published in Journal of Hydrology 374 (2009) 384-396)

[7] López-Moreno, op. cit.

[8] Giorgio. F., Lionello, P. (2008), “*Climate change projections for the Mediterranean region*”. Published in Global and Planetary Change 63 (2008) 90-104

extremely high temperature events and heat waves, the consequences of which on the energy system will be discussed later in this paper.

Tuck et al (2006)[9] have modelled the possible impact of higher mean temperatures on the availability of **biocrops** in Europe, concluding that “Mediterranean oil and solid biofuel crops, currently restricted to southern Europe, are predicted to extend further north due to higher summer temperature”.

***Graph: Northward migration of “biocrops”***

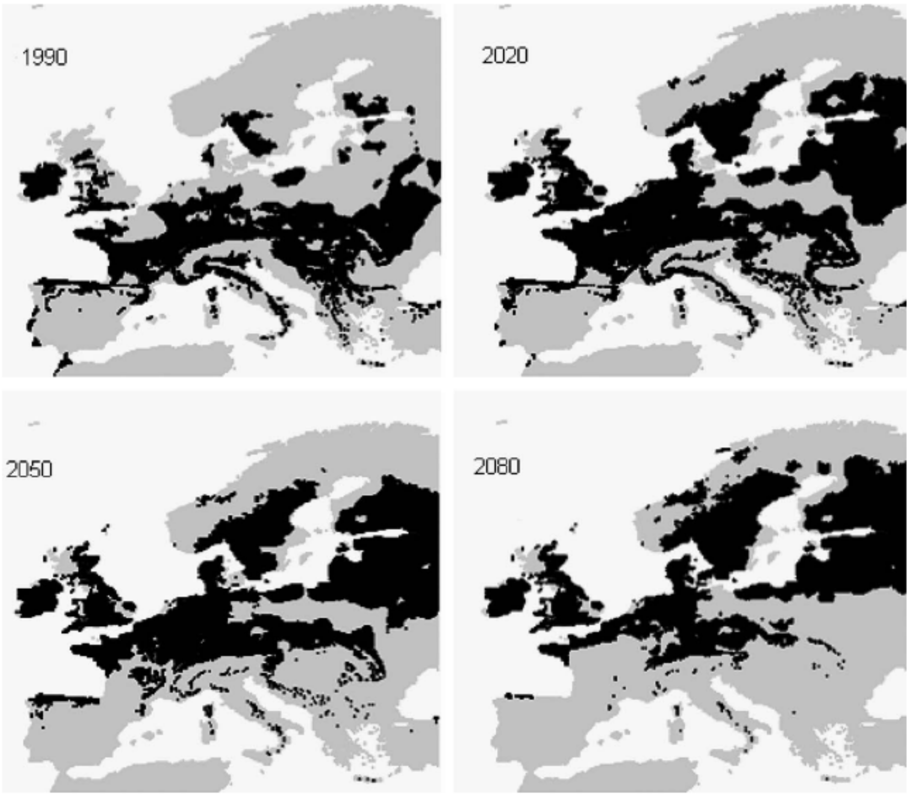


Fig. 3. Climate suitability maps for hemp, as predicted by the HadCM3 model and the A2 scenario, showing the baseline distribution (1990), and the change with time, for the time slices 2020s, 2050s and 2080s.

*Source: Tuck et al (2006)*

While for the major part of Europe, the effects of climate change on biocrop production are expected to be positive, the Southern region, comprising parts of France, Portugal, Greece and, especially, Spain, will see their potential for biocrop production “severely impaired”: “If bioenergy crops are to be viable in these vulnerable regions in the future, efforts such as breeding for temperature/drought tolerance or alternative management strategies (e.g. earlier sowing) will be required to allow bioenergy crop production to adapt to the challenges presented by climate change.” (Tuck et al 2006).

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[9] Tuck, G.,Glendining, M., Smith, P., House, J. Wattenbach, M. (2006) “*The potential distribution of bioenergy crops in Europe under present and future climate*”. Published in Biomass and Bioenergy 30 (2006) 183–197

**Near shore and off-shore energy facilities** may be affected by the rise of the sea level, as documented by Estonian researchers[10]. The worrying example has been the former uranium enrichment plan in Sillamäe, from which radioactive substances leak into the soil and sea. The facility is protected by a dam, which, in case of destruction, could cause catastrophic pollution in the Gulf of Finland.

Sea level rise could also affect the foundation loading of off-shore wind facilities, which tend to be built in shallow waters[11]. Further climate change impacts on the **wind energy sector** are presently little explored and wind resource magnitudes are not expected to become severely affected in the short and medium term, since wind speeds are generally variable, with annual variation of 10 - 15%. However, small changes in a given location could have an important – positive or negative – impact on the production of wind parks, since a change in wind speed at turbine hub-height of 0.5 m s leads to an increase in energy density by over 30%. In general, with regard to wind energy, experts expect to see "winners" and "losers" – regions where wind energy development may benefit from climate change and regions, where the wind energy industry may be negatively impacted.

Some efforts are under way to measure and predict wind speeds more precisely and thus support siting decisions for new wind farms[12]. According to the new measurements available, wind speeds in the Southern half of the North Sea are rapidly increasing during summer time, so that energy outputs are up 50% compared to 1990 levels[13]. However, wind speeds are also becoming lower in other regions and this data needs to be taken into account for sites with a wind potential that is close to the lower threshold of 5 m s, which wind turbines need to operate.

Further uncertainties are related to the possible need of design changes in the turbines to withstand extreme weather events or the possible, positive effect of declines in sea ice and icing frequencies in Northern locations, which are presently not appropriate for installing wind parks. Finally, the expected pole-ward displacement of storm tracks and fewer, but more intense mid-latitude cyclones may have to be considered in the planning phase of wind parks.

Storms pose a dangerous threat to **off-shore and near-shore facilities**, as hurricane Katrina and other recent events have demonstrated. This

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[10] Kont, A., Jaagus, J. Aunap, R. (2003), „*Climate Change Scenarios and the effect of sea level rise for Estonia*". Published in Global and Planetary Change 36 (2003) 1-15

[11] Pryor, S.C., Barthelmie, R.J. (2009), "*Climate change impacts on wind energy: A review*" Published in Renewable and Sustainable Energy Reviews (2009)

[12] See The Guardian, 26/04/09, "*Winds of change blow for offshore power operators*"

13 Atmos Counsulting (2009), "*Windscan. Recent Research Findings*", May 2009

includes gas and oil production platforms, but may extend in the future to off-shore wind parks and, especially, ocean power projects. The resistance of off-shore wind parks to hurricanes is already being considered in the authorization procedure and planning phase of projects in the US[14]. Models are available to take the likelihood of hurricanes into account when analysing the financial viability of off-shore wind parks[15], but it is not clear if the reference values for decision-making consider the likelihood of more extreme conditions or are based on historical data. **Ocean power technologies** have not yet reached the same stage of large-scale deployment, but may offer interesting opportunities for coastal regions in the medium future. Companies are presently testing the resistance of different pilot technologies to storms and wave heights, and it is clear that robustness will be one of decisive elements for the competiveness of the winning technologies.

### 3.2. Impacts on Transmission and Distribution of Energy

Storms are also one of the main threats to the energy sector's transport and distribution system. For example, the storms of December 1999 in France destroyed significant parts of the French electricity system causing wide-spread blackouts. As a result, the French authorities decided to follow a new policy of undergrounding significant parts of their electricity system in order to secure supply availability under adverse weather conditions[16]. "Undergrounding" transport and distribution lines requires additional investment by the energy companies, but may be the more cost-effective solution in the longer term, preventing economic losses in the future. This will be especially important with the growing interconnection of the European electricity market, which implies the transport of larger quantities of electricity over longer distances. But it could also be important to better protect regions, which rely increasingly on autonomous energy production facilities and local networks.

The increasing risk of forest fires is another element to take into account, as recent events in Greece, Northern Portugal, Spain and other locations have shown. Grid failures can, for one hand, be the cause of these fires, but, on the other hand, the transport infrastructure can also be used for early fire detection with the help of advanced sensors.

The expected changes in energy demand patterns, which are explained below, will provoke problems in the form of peak loads in regions with

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[14] See, for example, the EPA environmental impact analysis of the Long Island Offshore Wind Park or the Bluewater project in Delaware.

[15] Stratford, Peter (2007), "*Assessing the Financial Viability of Offshore Wind Farms*", Contribution to the EWEC 2007 Conference

[16] European Commission (2003), "*Background Paper. Undergrounding of Electricity Lines in Europ*e"

increasing need for air-conditioning, especially in grids that are operating close to their maximum capacity.

### 3.3. Impacts on Energy Demand

There is a general agreement among researchers that increased mean temperatures will lead to a higher demand for cooling purposes and a lower demand for heating our buildings. Climate change will therefore have the greatest effects on the energy used for space heating and cooling, especially in the commercial sector. In industry, heating and cooling demands are often considered to be independent of outdoors temperatures[17], but this may not be true for specific industrial activities, for example cooling processes related to food production and storage[18]. Also, not all cooling and heating processes will be affected, since some of these are continuous (for example, the freezer at home) and may only require a slight increase of energy input. Much more important for future demand increases are the **temperature-related processes** in a building.

Heating and cooling demand of buildings is generally expressed in the shape of a U-curve, indicating that there is a range of outside temperature, generally set at 15.5 to 18-18.5º C, when a building does not need any type of energy input to be comfortable. Although 18.0º C may appear a low threshold, it must be kept in mind that buildings, and especially office buildings, receive residual heat from inside, for example from ICT applications. According to Swiss researchers[19], temperatures up to 29º C can be coped with by natural night ventilation, but only for a short-term period with an outdoor air temperature maximum of 36.7 º C. The need for mechanical cooling sets in during prolonged periods of heat, as experienced in large parts of Europe in 2003 and, in a more general form, in the Southern European regions. The most important effect of heat waves on the demand side will be the "Heat Island Effect" in certain urban areas, where heat is much more intense than in other environments.

Impacts on energy demand for heating and cooling are expected to be considerable, even in central Europe: in Switzerland, a 33-44% decrease in the annual heating energy demand is foreseen for the period 2050-2100 for residential buildings, but the cooling demand for office buildings will

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[17] Ruth, M., Lin, A. (2006), "*Regional energy demand and adaptations to climate change: methodology and application to the sate of Maryland, USA*". Published in: Energy Policy 34 (2006) 2820-2833

[18] Hekkenberg, M., Moll, H.C., Shoot Uiterkamp, A.J.M. (2009), "*Dynamic temperature dependence patterns in future energy demand models in the context of climate change*". Published in Energy (2009) 1-10

[19] Frank, Th. (2005), "*Climate change impacts on building heating and cooling energy demand in Switzerland*". Published in: Energy and Buildings 37 (2005) 1175-1185

increase by 223 - 1050%. There are, however, important regional differences[20] depending on the climate zone and the building quality, as well as cultural and sociological factors, which will be discussed later.

From the energy sector's point of view, the shift from heating to cooling demand implies, in most countries, a switch to greater electricity use and lower demand for gas, oil or other fuels used for heating. This means, that the strain on the electricity grid will increase during the summer months, but little benefits can be expected for other energy networks. The increase of annual electricity demand attributable solely to climate change is expected to be in the range of 3.6 – 5.5% in Greece[21]. Again, we find important differences within the country, being the most affected regions Attika and the central Macedonia regions, the Aegean Islands, Crete and the Thessalia prefecture[22].

When looking at the maximum mean July temperatures in the European regions over the last 15 years, as shown in the map below, the borderline between the most vulnerable regions in the South and the rest of continent becomes perfectly visible. Depending on the speed and intensity of climate change, this borderline is expected to move upward. The greatest increase in additional electricity demand for cooling is not likely to occur in the hottest regions, where air-conditioning is already quite common, but in regions with moderately hot summers (up to now).

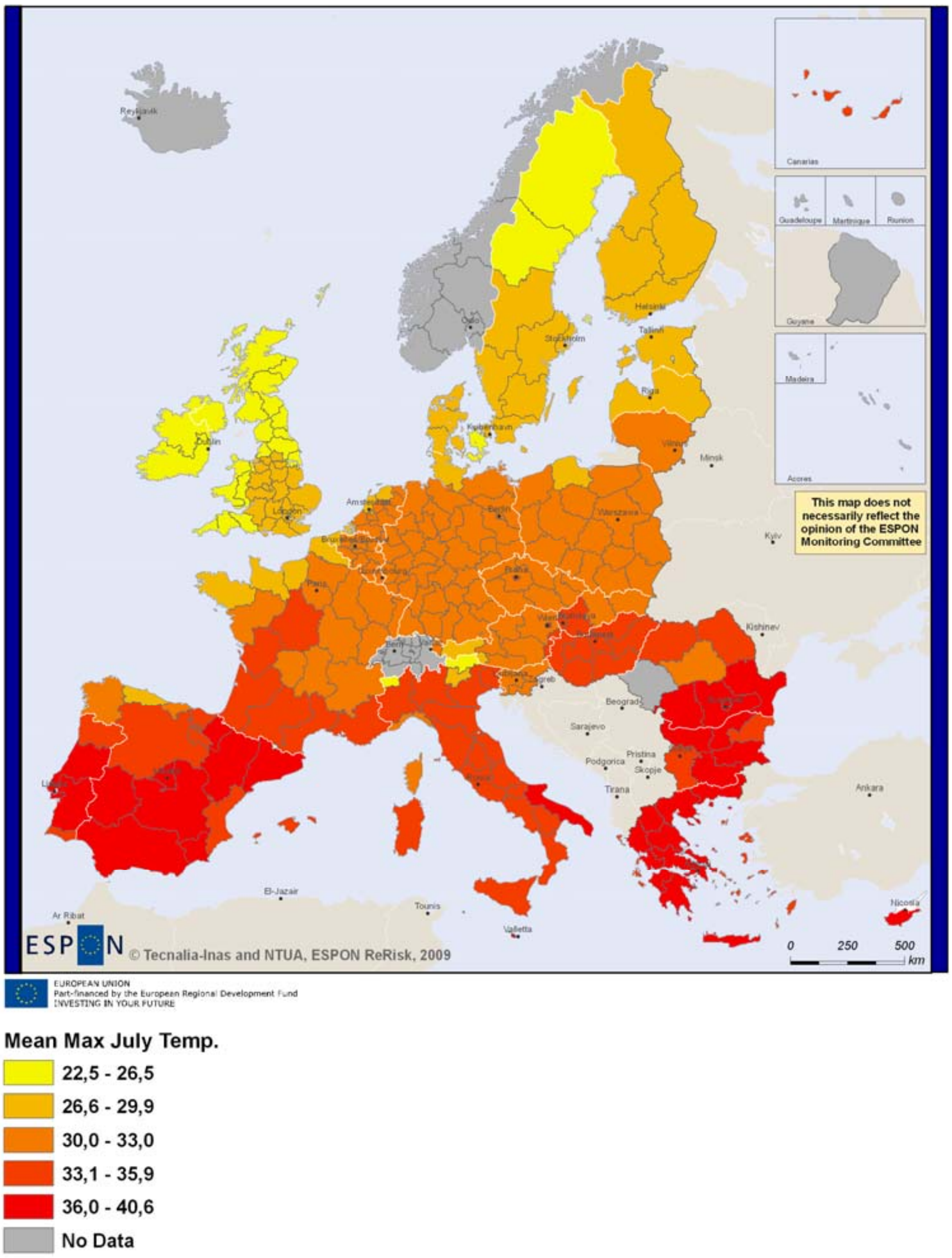
[20] Christenson, M., Manz, H., Gyalistras, D. (2006), "*Climate warming impact on degree-days and bulding energy demand in Switzerlan*d". Published in Energy Conversion and Management 47 (2006) 671-686

[21] Mirasdegis, S., Sarafidis, Y. Georgopoulou, E., Kotroni, V., Lagourvardos, K. Lalas C.P., (2007) "*Modeling framework for estimating impacts of climate change on electricity demand at regional level: Case of Greece*." Published in: Energy Conversion and Management (2007) 1737-1750

[22] Cartalis, C., Synodinou, A. Proedrou, M. Tsangrassoulis, A., Santamouris, M. (2001), "*Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region*". Published in Energy Conversion and Management 42 (2001) 1647-1656

***Map: Regions with Highest Summer Temperatures in Europe***

Mean Maximum July Temperature (o Celcius)




*Source: ESPON ReRisk Project. Elaboration: NTUA, based on JRC data*

The critical question for the future energy demand for cooling consists in the number of persons who will make increased use of air-conditioning, as temperatures climb beyond the “range of comfort”. This range is not precisely defined and is obviously related to personal preferences and cultural settings. Comparative research on the air conditioning market saturation in 39 US cities[23] that there are several determinants for air-conditioning use, others than temperature:

- Household income
- Household size
- Electricity price

Other aspects influencing consumer behaviour and, therewith, future energy demand are.

- The quality of the building stock and the design of the specific building
- The ICT equipment used in building and the amount of residual energy emitted[24]
- Deployment of energy-efficient appliances[25]
- The percentage of elderly population in a region, which is more affected by heat waves
- Legislation, such as the Swiss National Standard SIA 382, which defines a minimum threshold for the installation of air-conditioning appliances in office buildings[26].

These non-climate factors combined and the socio-economic dynamics behind them are likely to have a greater effect on the development of energy demand for cooling than the impacts of climate change. They also set the frame for policy interventions on regional level.

**Conclusions and recommendations for regional policy makers**

Although the extent and the speed of climate change impacts on the energy sector are not known at the moment and all data presented here relies in the interpretation of the rather conservative IPCC scenarios, a quite coherent picture arises, when analysing the modelling results.

Impacts are likely to be severe in the Southern regions belonging to Spain, Greece, Portugal and France, both in terms of energy production and

[23] Sailor, D.J., Pavlova, A.A. (2003), “*Air conditioning market saturation and long-term response of residential cooling energy demand to climate chang*e”. Published in Energy 28 (2003) 941-951
[24] Heckenberg, M et al (2009), op cit.
[25] Heckenberg, M et al (2009), op cit.
[26] Frank, T. (2005), op. cit

demand. In these regions, summers are going to be complicated for energy companies, due to diminishing water reserves, higher mean temperatures and heat waves, and consequently, forest fires. The supply problems will coincide in time with higher peaks of electricity demand, derived from a more extended use of air-conditioning.

Existing energy infrastructure is under risk in most parts of Europe and needs additional protection through **monitoring** or **undergrounding**. New capacity to be installed, including projects for the use of wind or bio- or ocean energy, also has to be scrutinized for possible **vulnerabilities** to climate change impacts. The need for new, expensive and under-used peak load capacities for electricity production will be greatest in regions, which have not yet reached full market saturation of air-conditioning appliances. However, much of this may be avoided by promoting **passive cooling techniques** or **solar-based appliances** in buildings and cities or by **defining a minimum threshold** for their installation in offices and public buildings.

One recommendation is that **environmental risk assessment** must be extended: "It is not enough just to assess an installation's impact on the environment; one must also assess the impact of a changing environment on the installation. Then, as much as possible, the impact of that change must be integrated into planning and countered"[27]. This is especially important for coastal zones, according to the Portuguese agency CCDRN[28]. Regions near the shore could make use of the tools related to the Integrated Coastal Zones Management (ICZM) to reduce their vulnerability to climate change effects.

However, all European regions need more accurate and "down-scaled" scenarios to make the right long-term planning decisions.

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[27] Paskal, Cleo (2009), "*The Vulnerability of Energy Infrastructure to Environmental Change*". Published in Chatham House Briefing Paper, April 2009
[28] CCDRN Comissão de Coordenação e Desenvolvimento Regional do Norte

Reference Projects for further reading:

Climate change and water scenarios: Downscaling to EU Regions: ENSAMBLES http://ensembles-eu.metoffice.com/

PRUDENCE Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects
http://www.cru.uea.ac.uk/projects/mps/html/prudence.html

SCENES: Water Scenarios for Europe and for Neighbouring States
http://www.environment.fi/default.asp?contentid=334927&lan=EN

EEA (2009), “Regional climate change and adaptation — The Alps facing the challenge of changing water resources”, EEA Report No 8/2009

ADAM Adaptation and Mitigation Strategies to Climate Change (final report published in June 2009)
http://www.adamproject.eu/