

Assessment of the impacts under future climate change on the energy systems with the POLES model

Silvana Mima, Patrick Criqui

▶ **To cite this version:**

Silvana Mima, Patrick Criqui. Assessment of the impacts under future climate change on the energy systems with the POLES model. International energy workshop, Jun 2009, Venise, Italy. halshs-00452948

HAL Id: halshs-00452948
https://shs.hal.science/halshs-00452948

Submitted on 3 Feb 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

2009 International Energy Workshop

17-19 June

Fondazione Giorgio Cini, Venice, Italy

Assessment of the impacts under future climate change on the energy systems with the POLES model

Silvana Mima

Patrick Criqui

LEPII, CNRS, Université Grenoble 2

1. Introduction

Through increases in average temperatures, changes in precipitations, more frequent extreme weather events, climate change is expected to have major impacts on economic systems, including energy. Understanding the climate change-energy nexus is becoming an emerging issue of national and international concern. Nevertheless significant uncertainties exist about the potential impacts of climate change on different elements of the energy systems, because the timing and magnitude of the climate impacts at regional level, the intensity of extreme weather events and the possible changes in regional water supply regimes. A relative lack of research in this domain makes difficult the assessment of climate change effects on future energy demand and supply.

An overview of what is currently known allows identifying four key areas for impacts of climate change on the energy sector:

i. energy for thermal comfort in buildings,

ii. changes in hydro energy resources and production,

iii. constraints in thermal power production and

iv. increased energy needs for water supply.

Other renewable sources of energy may be affected by a changing climate as well, but in a still less predictable way: solar technologies are affected by cloud cover and solar insulation, while changes in wind patterns may impact future wind power generation. Because of important uncertainties the impacts on these technologies are not currently taken into account into the POLES model.

POLES modelling system provides a tool for the simulation of world energy scenarios under environmental constraints. It is not a General Equilibrium, but a Partial Equilibrium Model, with a dynamic recursive simulation process. From the identification of the drivers and constraints in the energy system, the model allows to describe the pathways for energy development, energy demand, fuel supply, greenhouse gas emissions, international and end-user prices, from today to 2100.

In this paper we summarize the modification on different modules that have been introduced in order to take into account the above identified climate change impacts on the energy systems. After the introduction, the paper presents the main features and adaptations of the POLES model with details on the treatment of the electricity demand in the residential and service sector, of the hydro and thermal electricity generation and energy demand for water supply while using climate drivers coming from other models. Each section presents and compares the results of the Reference projection with and without the taking into account of the effects of climate change on energy systems for the World and for Europe (EU27) up to 2100.

2. Impacts of climate change on building energy demand

Weather and climate may affect all major aspects of the electric power sector, including electricity generation, transmission and distribution systems, and end-user demand for power. On the demand side, warmer winter temperatures in cold regions may reduce the demand for energy because less space heating will be required. On the other hand, higher temperatures during summer months in warm regions will lead to more demand for electricity to run air-conditioners and refrigerators. In order to assess these effects, the existing POLES demand model has been improved for setting apart the demand affected from climate change. This demand is then modified by taking into account heating degree days (HDD) and cooling degree days (CDD) provided by the IMAGE/TIMER model, in the framework of a world where the average temperature may increase of +3.7°C compared to pre-industrial ages (or a concentration level of 771 ppmv in 2100).

2.1. Methodology

First of all, we isolate the demand for heating from the demand for substitutable energy (heating, cooking and sanitary hot water) in the residential sector. In this way, final consumption for substitutable energy in residential sector (FCSENRES) is split into two parts: on the one hand, the demand that can not be impacted by climate change (FCSENRESW) and on the other hand the demand that will be affected (FCSENRESH):

$$FCSENRES_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESH_{[ALLC]}$$

The shares (SHRES) of the part of heating demand on the substitutable energy, computed from data found in the existing literature, helps to accomplish this separation. Then we estimate the climate change impact on the heating demand (FCSENRESHCC**)** based on heating degree days (HDD) provided by Timer/IMAGE.

$$FCSENRESHCC_{[ALLC]} = FCSENRES_{[ALLC]} * SHRES_{[ALLC]} * \frac{HDD_{[ALLC]}}{HDD_{2005[ALLC]}}$$

In this way, the new demand for substitutable energy taking into account the climate change is :

$$FCSENRESCC_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESHCC_{[ALLC]}$$

The same methodology is used for the service sector.

The data for the base year (2005), for SHRES and SHSER**,** for each POLES region, are built using several sources such as Enerdata, Eurostat 2005 for temperature correction. Then a logarithmic regression is applied between SHRESH and HDD and GDP (assuming the equivalence between spatial and temporal regression):

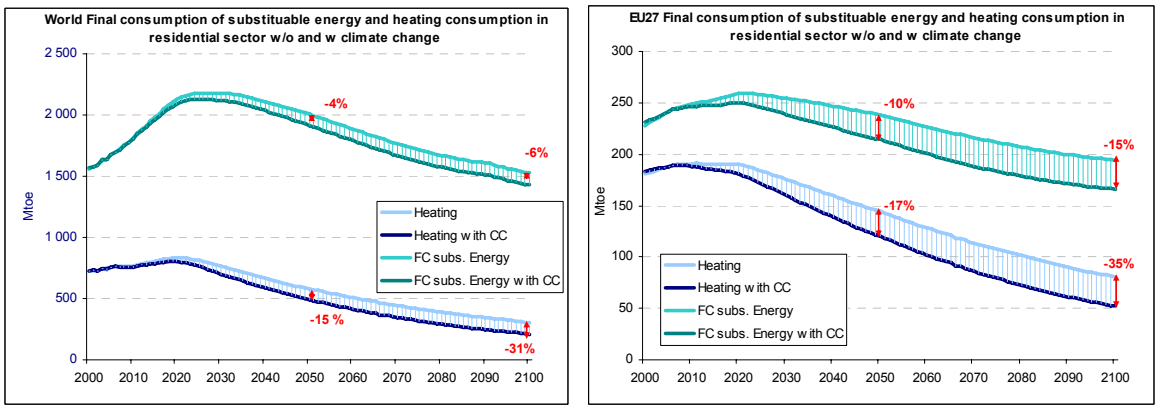
$$SHRES_{[ALLC,\,T]} = SHRES_{[ALLC,\,T-1]} * \left(\frac{GDPPOP_{[ALLC,T]}}{GDPPOP_{[ALLC,T-1]}}\right)^{0.06} * \left(\frac{HDD_{[ALLC,T]}}{HDD_{[ALLC,T-1]}}\right)^{1.58} \quad (1)$$

$$SHSER_{[ALLC,\,T]} = SHSER_{[ALLC,\,T-1]} * \left(\frac{GDPPOP_{[ALLC,T]}}{GDPPOP_{[ALLC,T-1]}}\right)^{0.02} * \left(\frac{HDD_{[ALLC,T]}}{HDD_{[ALLC,T-1]}}\right)^{1.47}$$

- ***Results***

The increase in temperature clearly curtails the heating demand. The comparison of the heating demand in the residential sector, with and without climate change impacts, shows a gap which enlarges in time going from -15 % by 2050 to -31% by 2100 at world level and from -17% to -35% for the EU27 level. This shrinkage of the heating demand translates into a reduction of the substitutable energy demand by -4% at world level and -10% in the EU27 level by 2050 and respectively, -6% and -15% by 2100. The results in the service sector are quite comparable.

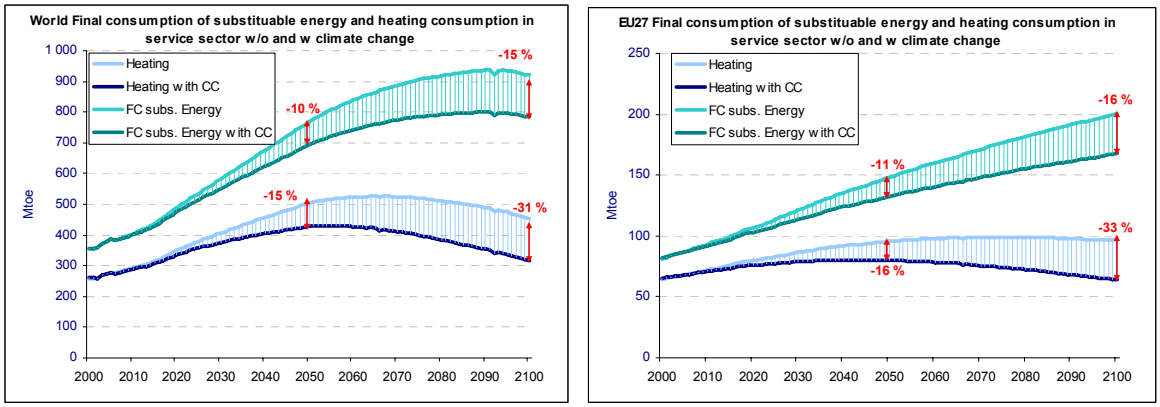
Figure 1 : Final consumption of substitutable energy and heating consumption in the residential sector without and with climate change



Source : POLES REF

1 The coefficient of determination is respectively 0.85 and 0.82 for the residential and service sector.

Figure 2: Final consumption of substitutable energy and heating consumption in the service sector without and with climate change



Source : POLES REF

- *Modelling the impacts of climate change on cooling demand*

The method proposed to model the impact of climate change on residential cooling demand is based on the paper by McNeil and Letschert (2007). We model the impact in two steps, firstly the modelling of the air-conditioner ownership and then the modelling of the average baseline unit energy consumption.

The air-conditioning equipment rate (ACER) is the multiplication of the climate maximum saturation rate (CMAX) by the air-conditioning availability (AVRES). Climate maximum saturation is depends on the cooling degree days (CDD). For example, for the USA the climate maximum saturation (CMAX) can be calculated with the following relationship:

$$CMAX_{[USA]} = 1 - 0.949 * e^{(-0.00187 * CDD)}$$

Residential Air Conditioning Availability (AVRES) is dependent on revenues following a logistic S-curve: $AVRES = 1 / (1 + e^{(3.77610543)} * e^{(-0.22537608 * GDPPOP)})$ ([2])

Than saturation is: $ACER = CMAX * AVRES$

The air-conditioning unit energy consumption (ACUEC**)** depends on cooling degree days, but there is a significant dependence on income as well. The following equation was refitted with POLES data:

$$ACUEC = CDD * (a * \ln(GDPPOP) + b)$$

This equation is proposed in the paper of Morna Isaac and Detlef Van Vuuren, which is derived from McNeil. The logarithm takes into account saturation for high income levels.

---

2 Model refitted with POLES data. R2 = 0.66

$$ACUEC_{(t)} = ACUEC_{(t-1)} * \frac{CDD_{(t)}}{CDD_{(t-1)}} * \frac{(a * \ln(GDPPOP_{(t)}) + b)}{a * \ln(GDPPOP_{(t-1)}) + b)}$$

Where : $a = 7.2651*10^{-0.8}$, $b= 8.7398 * 10^{-0.5}$

Finally, the air conditioning electricity consumption with climate change impact (FCCELRESCC) is calculated as production of climate maximum saturation (CMAX), residential air conditioning availability (AVRES), the air-conditioning unit energy consumption (ACUEC) and the number of dwellings (DWL):

$$FCCELRESCC_{[ALLC]} = CMAX_{[ALLC]} * AVRES_{[ALLC]} * ACUEC_{[ALLC]} * DWL_{[ALLC]}$$

The total captive electricity including the air conditioning:

$$FCCELRESTOT_{[ALLC]} = FCCELRES_{[ALLC]} - FCCELRESCC_{[ALLC]}2005 + FCCELRESCC_{[ALLC]}$$

Where :

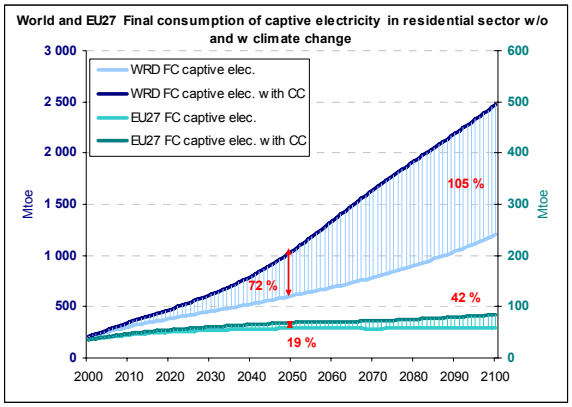
- The Cooling Degree Days (CDD) data come from Timer/IMAGE, for reference scenario (771 ppmv in 2100, +3.7°C since pre-industrial ages).
- The air conditioner saturation data and the unit energy consumption data come from the paper by McNeil and Letschert.
- The GDP per capita and the dwellings come from POLES : GDPPOP, DWL.

- ***Results***

The net effect of climate change on global energy use and emissions is relatively small, as the increases in cooling are compensated for by the decreases in heating. However, impacts on heating and cooling individually are considerable in this scenario, with heating energy demand decreasing by 31% worldwide by 2100 as a result of climate change, and air conditioning energy demand increasing by 105%. At the regional scale, considerable impacts can be seen, particularly in Latin America, where energy demand for residential air conditioning could increase by around 260% due to climate change, compared to the situation without climate change.

The paper of Isaac and van Vuuren (2009) presents comparable results: with heating energy demand decreased by 34% worldwide by 2100 as a result of climate change, and air conditioning energy demand increased by 72%.

Figure 3: World and EU27 final consumption for captive electricity and air conditioning in the residential sector



Source : POLES REF

3. Impact of Climate Change on hydropower Generation

Hydropower plants are also affected by climate change. Factors such as timing and geographical pattern of precipitation, temperature, snow-melting affect stream flow and reservoir levels. While precipitation changes may show increasing as well as decreasing trends, depending on the geographical area and the season, evaporation is expected to rise due to ascending temperatures. Hence, considerable changes in discharge regimes are expected for the future as a consequence of climate change. Moreover, not all countries are equally affected because some are more reliant on hydroelectricity than others.

Hydropower is currently the major renewable source contributing to electricity supply in most countries. Five (Brazil, Canada, China, Russia and the USA) account for more than half of global hydropower production. In 2007, hydro-electric generation accounted for 16% of world power generation. During 2007, 26 GW of new hydro capacity came into operation, bringing total world hydro capacity to nearly 919 GW. Hydro-electric generation during the year was in excess of 3 TWh, representing some 34% of the world's proved recoverable hydroelectricity resources. Its future contribution is anticipated to increase significantly.

Hydropower now makes up a significant percentage (about 20%) of the total installed capacity for electricity generation in Europe, and there is strong motivation to expand this capacity especially in Southern and Eastern Europe in order to provide electricity for economic growth.

Different studies provide many examples of the impacts of the climate change on the hydroelectricity production during the last years. For e.g. in the Northern Europe higher temperatures are expected to be accompanied by up to 40% more rain, intense precipitation and storms, leading to higher risks of flash floods and damage to infrastructure

3.1. Methodology

In order to take into account the future climate change impacts on hydroelectricity, we rely on information about changing hydro power potential available in the literature, for European countries, and in the changes in the precipitations provided by IMAGE/TIMER model. Thus, two modifications of the POLES model must be underlined: a. climate change impacts on available capacity factor for existing hydropower capacities which permits to calculate the impact in terms of hydro generation and b. changes of the hydropower technical potentials on the construction of the new capacities.

$$ACAF_{[ALLC,HYD]}=ACAF\ DAT_{[ALLC,HYD]}*\left(\frac{Rain_{[ALLC]}}{Rain_{2005[ALLC]}}\right)$$

$$EXPW\ HYD_{[ALLC]}=ACPW_{[ALLC,HYD]}*(1+HYDCOEF_{[ALLC]})^{10}*\left(\frac{Base\,price_{[ALLC]}}{Base\,price\,dly_{[ALLC]}}\right)^{HYDPE_{[ALLC]}}$$

Where :

$HYDCOEF_{[ALLC]}$ = IF ($EPHYT_{[ALLC]}$ > 0.85* $RSVHYD_{[ALLC]}$,

THEN 0,

ELSE $HYDTRIP_{[ALLC]}$)

$HYDPE_{[ALLC]}$ - Price elasticity of hydro expected capacity

Capacity trend for hydro:

$HYDTRIP_{[ALLC]}$ =(($RSVHYD_{[ALLC]}$*($rain_{[ALLC]}$/$rain2005_{[ALLC]}$)-$EPHYT_{[ALLC]}$)

/($RSVHYD_{[ALLC]}$*($rain_{[ALLC]}$/$rain2005_{[ALLC]}$)))/100

An important aspect of the projections performed with the POLES model is that they rely on a framework of permanent competition between technologies with dynamically changing attributes. The expected cost and performance data for each critical technology are gathered and examined in a customised database that organises and standardises the information in a manner appropriate to the task. Although the model does not calculate the macro-economic impacts of mitigation scenarios, it does produce robust economic assessments based on the costs of implementation of new technologies and that benefit from a rigorous examination of the engineering and scientific fundamentals.

The shape and volume of the electrical load and the cost and performance of available generating technologies determine investment in the power sector. The capital costs and performance characteristics of each technology are stored in the TECHPOL database and the fuel costs are endogenous to the model. The model simulates the total electricity demand and load curve to a t+10 years horizon by extrapolation.

Levelised electricity costs are calculated for each technology at six reference load factors from 730 to 8760 hours. Capacity expansion in each national system is then assumed to be defined by the least-cost investment to meet the expected load duration curve at t+10, taking into account

existing plants. Primary electricity sources, such as hydro and nuclear electricity, supply the base-load. Other technologies compete to supply the remainder of the base-load and the rest of the load curve. After the capacity expansion is determined the model then calculates the production mix of electricity from the given capacity structure by loading plants in order of their operating cost (the merit order) until the demand is satisfied. Finally, the average production cost is derived from the production mix and the levelised costs of the plants.

The utilization of hydroelectric plants typically depends on the available water supply, which varies considerably by region and season. In that way, the capacity expansion is function of the technical potential and the gap between the hydroelectric production cost and the electricity price of the baseload.

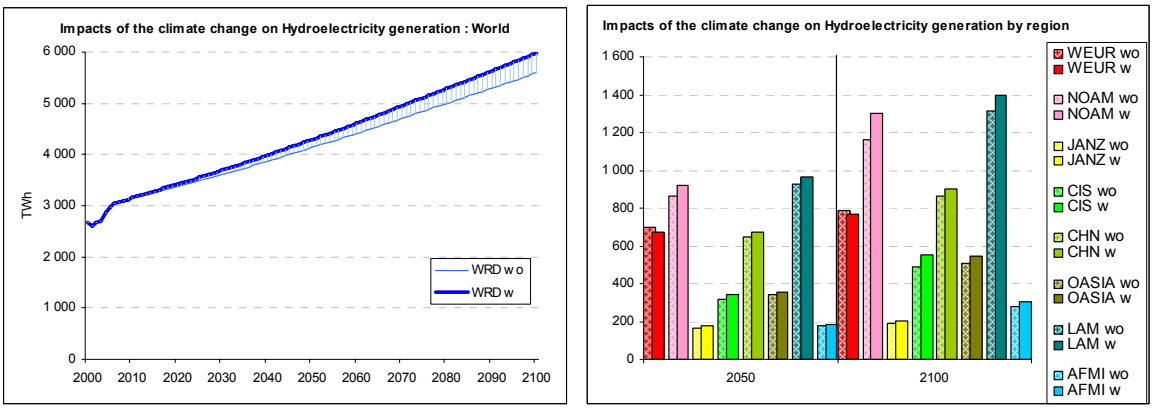
The small hydro electricity module in POLES is essentially a dynamic Fisher-Pry model, with an endogenous economic potential and an endogenous diffusion time-constant. What this means is that the amount of generation from small hydro is determined by a logistic function that relates the generation to the economic potential and the maturity of the technology through parameters that vary according to the technology's cost-effectiveness. The economic potential is the share of the technical potential that is economically competitive under the conditions simulated in the model. This share is calculated as a function of the average payback period for the investment - the lower is the payback period the larger the share of the technical potential that is economic. So the change of the technical potential because of the climate change affects also the economic potential and as consequence the hydroelectricity generation.

We use the study carried out by Lehner et al. (2005) that estimates the impact of climate change on hydro power potential for Europe at a country level. The authors calculate the influence of climate change on the gross hydro power potential as well as its impact on the already developed hydro power capacity. Results obtained within the mentioned analysis indicate decreasing discharge volumes for southern and east-central Europe by more than 25 % in some countries, whilst the foreseen rises in discharge volumes for northern European countries may at times exceed 25 %. In addition, one should consider that hydro power production is characterised by a high annual variability which may even cause higher changes on an annual basis.

3.2. Results

Preliminary results show an average increase of the world hydro electricity generation because of the global climate change of 3.7% and 6.8%, respectively in 2050 and 2100, (see Figure 4). This impact varies from region to region. There are some regions, where hydroelectricity generation increase because of the climate change as in the northern America (7%, 12%), CIS (8%, 13%), Japan & Australasia (7%,6%), while in Western Europe decrease respectively -3.7%, -2.4%) .

Figure 4 : Impacts of the climate change on the hydroelectricity generation

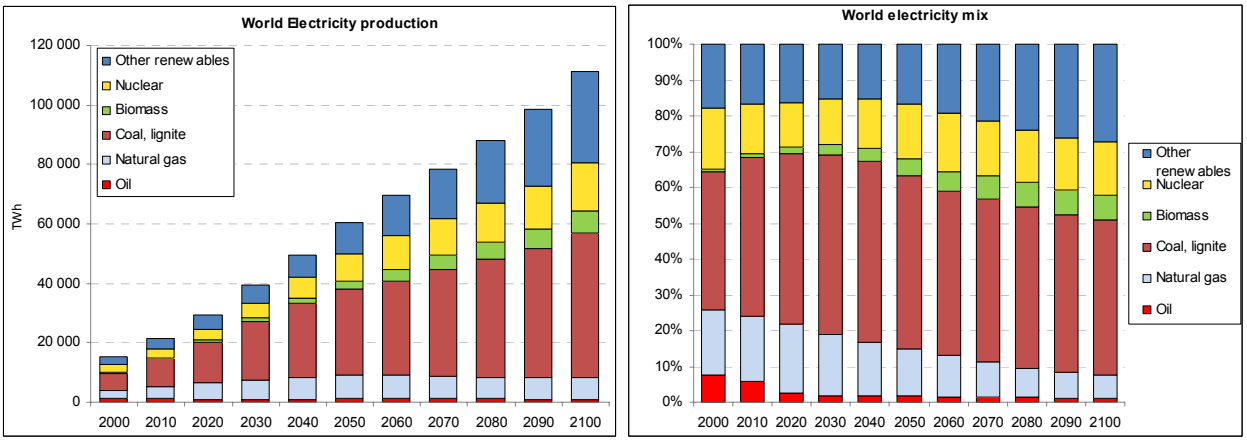


Source : POLES REF

4. Impact of Climate Change on the thermal power generation

Conventional thermal and nuclear power stations provide more than 80% of the electricity. Although this role is foreseen to decrease to nearly 70% in 2100 in POLES reference case, their production attains 80 000 TWh in 2100, which represents 5 times the current production. But climate change is likely to constrain thermoelectric generation in the 21st century by degrading cooling capability and power plant efficiency.

Figure 5 : World electricity production and mix (2000-2100)



Source : POLES REF.

Conventional thermal and nuclear power stations are major users of water cooling and ongoing maintenance. The amount of water used for power plant cooling also varies by each specific power plant's electricity generating technology and size. For example, nuclear reactors require the most water for cooling, and baseload fossil fuel power plants come in second.

Thermoelectric power generation will be vulnerable to fluctuations in water supply. “While there is uncertainty in the nature and amount of change in water availability in specific locations, there is agreement among climate models that there will be a redistribution of water as well as changes in the availability by season” (Wilbanks & alii., 2008). Historically, summertime weather extremes have

required throttling or shutdown of thermoelectric units to comply with environmental or safety limits on water temperature. Thermoelectric power plants also become less efficient when the ambient air temperature increases.

4.1. Methodology

The currently available research literature on this subject is limited. Two temperature effects due to climate change are influencing the output of thermal power plants and are considered in the model calculations for the described Reference Scenario. On the one hand, higher temperatures of power plant cooling media influence the efficiencies of the plants. The efficiency decrease was derived and implemented in POLES for all types of thermal power plants using the input of the ADAM work package Scenarios (temperature values for the Reference Scenario) together with assumptions for efficiency calculations based on research literature. Durmayaz et al. (2006), roughly estimates that "the impact of 1°C increase in the temperature of the coolant extracted from environment is predicted to yield a decrease of ~ 0.45 and ~ 0.12% in the power output and the thermal efficiency of the pressurized-water reactor nuclear-power plant considered, respectively".

As it is underlined in the previous section, POLES model is characterised by a detailed representation of electricity generation technologies. So the model permits to take into account the impact of climate change into the availability and efficiency of the thermal technologies. However, first it is necessary to derive river temperatures from air temperatures. Mohseni & Stefan (1999) propose some linear regressions of stream temperature versus air temperature to asses the impact of higher air temperatures on water temperatures in rivers.

Two intermediary variables are calculated to take into account the impact of climate change into the availability and efficiency of the thermal technologies:

Coef thermal $ACAF_{[ALLC]}$=IF $CDD_{[ALLC]}$<=$CDD2005_{[ALLC]}$, THEN 0,

ELSE ImpACAF for $1°C_{[ALLC]}$*($CDD_{[ALLC]}$-$CDD2005_{[ALLC]}$)* Temp air $water_{[ALLC]}$

Coef thermal $ACEF_{[ALLC]}$=IF $CDD_{[ALLC]}$<=$CDD2005_{[ALLC]}$, THEN 0,

ELSE ImpACEF for $1°C_{[ALLC]}$*($CDD_{[ALLC]}$-$CDD2005_{[ALLC]}$)* Temp air $water_{[ALLC]}$

where:

Temp air $water_{[ALLC]}$ (0.7 in our case) changes of river temperatures from air temperatures.

Imp ACAF for $1°C_{[ALLC]}$ and Imp ACEF for $1°C_{[ALLC]}$ - the impact of 1°C increase in the temperature of the coolant extracted from environment into availability and efficiency of thermal power plants

Then the new availability and efficiency of the thermal technologies are :

$ACAFcc_{[ALLC,Tech]}$ = $ACAF_{[ALLC,Tech]}$ *(1- Coef thermal $ACAF_{[ALLC]}$)

$ACEFcc_{[ALLC,Tech]}$= $ACEF_{[ALLC,Tech]}$ *(1- Coef thermal $ACEF_{[ALLC]}$)

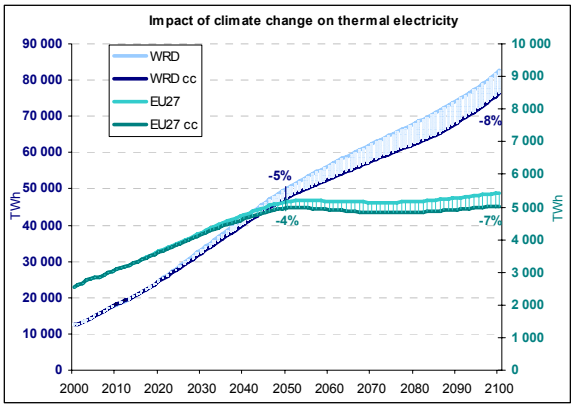
Other parameters which are influenced and depicted in the model under changed climate conditions are the efficiency of the transmission and distribution lines. In that perspective efficiency-losses for transmission lines based on the paper of Zhelezko et al. (2004) has been considered.

4.2. Results

Two kinds of results are interesting to show: The impact of the climate change on thermal electricity generation and on water withdrawals.

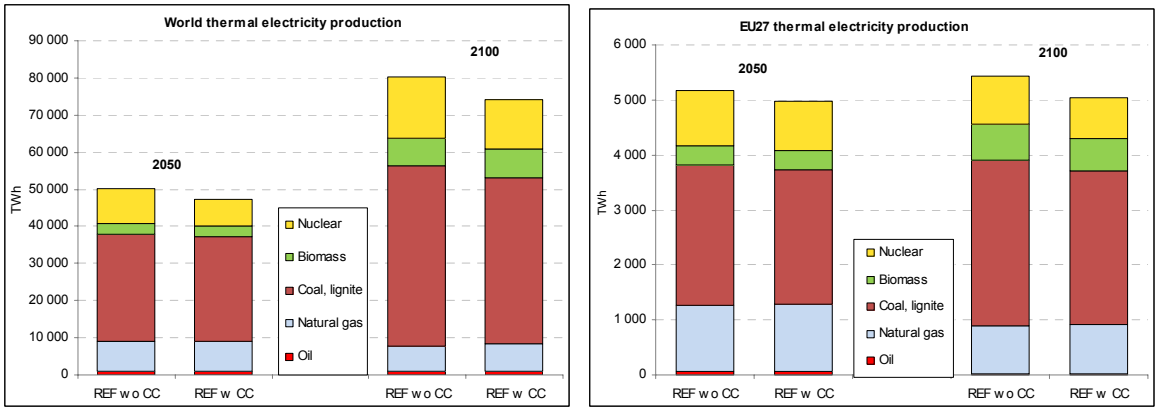
Apparently the impact seems minor, particularly up to 2050. In 2100 world and EU27 thermal electricity generation is -8% and -7% % lower than in the case without taking into account the impact of higher temperature (Figure).

Figure 6 : The impact of the climate change on thermal electricity generation



The decrease of the efficiency and availability of the power plants because of the climate change impact differently the competition between technologies. In world level oil (-23%) Coal (-7%) and nuclear (-19%) technologies are impacted negatively, while gas electricity production (13%) is more important in the second case. In European level the tendencies are similar.

Figure 7 : The impact of the climate change on thermal electricity generation by technology

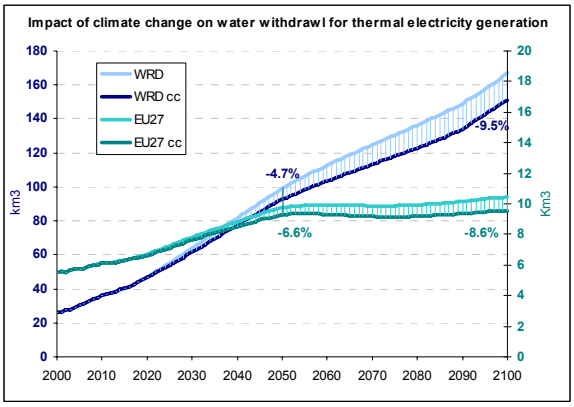


Source : POLES REF

The decrease of the electricity production is accompanied by a decrease of the water consumption for cooling thermal power plants Figure .

Ecological concerns are returning to cooling water system design and operation. Once-through systems require the intake of a continual flow of cooling water. The water demand for the once-through system is 30 to 50 times that of a closed cycle system. In 2000 for example, open-cycle cooling systems accounted for 91 percent of water withdrawals for thermoelectric cooling water in the U.S. in 2000 (Hutson et al. 2004). Characterising the adoption of new advanced cooling technologies in POLES model will be done through the introduction of the competition between different cooling technologies. For that reason more detailed information on their cost and performances is under preparation in TECHPOLES database.

Figure 8 : The impact of the climate change on water withdrawals for thermal electricity



Limited water availability and waste heat assimilative capacity can constrain the development of new thermoelectric generation. This fact is difficult to take into account in POLES model for the moment because we have not yet the possibility to introduce the competition between different uses of water.

5. Impact of Climate Change on the energy use for water supply

Water is indispensable to any kind of terrestrial life and significant quantities of energy are used in each country to access, treat and manage water. Electricity consumption for this purpose is comparable to several other industrial sectors: for eg. USA and France consume respectively around 214 and 19 TWh/year, representing 6.3 and 4.4% of total final electricity consumption (Goosens and Bonnet, 2001). In the Mediterranean countries this figure varies from 5 to 10%. (Thivet, 2008).

Fast growing demand for clean and fresh water and water shortages in many regions of the world impact inextricably electricity demand and supply. Climate change evidently, will impact differently not only each country and sector water withdrawals, but also water supply. “Climate change is expected to exacerbate current stresses on water resources. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate through the 21st

century, reducing water availability, hydropower potential, and changing seasonability of flows in some regions" (Intergovernmental Panel on Climate Change, Climate Change 2007: Synthesis Report). With stronger stress imposed in the future to water supply systems, in many regions of the world, electricity requirements for providing fresh water are expected to be more important.

In this framework, it seemed necessary to us, to include electricity demand for water withdrawals in the POLES model. For that reason, a water demand module, called GeoPol, is under construction in our Institute, aiming to project the water demand by sector use in each region of the POLES model. Exogenous data concerning the share of surface, underground, treated and desalinate water supply by country is under preparation as well. Furthermore, our technological database (TECHPOL) is enlarging with costs and performances of desalinated water technologies in order to better represent the competition between thermal and membrane processes. Many drivers affect electricity demand for fresh water: water demand, available water supply by source and technologies used to access, treat and manage water.

In order to meet the rising demand for drinking water in drier climate regions, desalination plants, which make salt water fit for drinking, are proposed as a way of solution. But the process is energy intensive and environmental damage can occur if brine water is returned to the sea. Many countries are increasingly relying on desalination to provide fresh water. Spain currently has 700 desalination plants, which provide enough water for 8 million people every day. Desalination is expected to double over the next 50 years in Spain.

The use of desalination would increase sharply in the next century, increasing the total available freshwater resource and, in this respect, may be preferable to further depletion of the surface and groundwater stocks. Detrimental environmental impacts are associated with desalination plants, however, in particular their energy consumption and the production of highly concentrated brine that may be released into sensitive marine waters. Furthermore, expanding supply from desalination plants does not provide any incentive to either reduce water use or improve the efficiency of use. Decisions on the suitability of future desalination plants need to be addressed on a case-by-case basis, accounting for all environmental and economic issues.

Renewable energy in the form of solar and wind power may also be used instead of energy derived from fossil fuels and salt may be extracted as a valuable by-product.

Some governments attempt to boost water supply through investing in projects such as reservoirs for storing water, water transfer and desalination plants.

5.1. Methodology

Water demand depends on population and economic growth, development patterns (more or less water intensive sectors), as well from average temperature (particularly irrigation needs, or cooling of thermoelectric power plants).

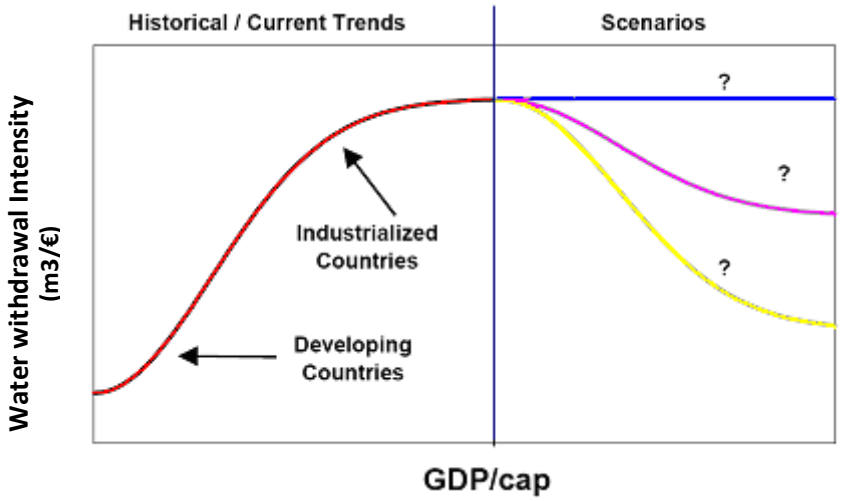
A first attempt has been done with POLES model to define water demand in country level, with and without climate change.

In the first block, water consumption without climate change is calculated from the relationship between the water intensity (water consumption per unit of GDP) and the GDP per capita, which usually follows an inverse U-shaped curve. The inverted U shape can be explained in terms of superposition of two trends of the changes in water requirements:

• Changes in different phases of the economic transition from agriculture to manufacturing and construction and then to services.

• Changes as a result of technological development.

Developing countries would be in the left side of the curve (with a positive slope, this situation corresponds to the first trend mentioned above), while developed countries would be in the upper side, while future evolution after a certain GDP/cap threshold will stabilise or continue with a negative slope.



Each country has its own intensity consumption pattern, PGwithdrawl (m3/k$), represented by the equation:

$$PGwithdrawl_{[ALLC]} = \left(\left(\frac{GDPPOP_{[ALLC]}}{GDPPOP\ dly_{[ALLC]}}\right)^{ACwater_{[ALLC]}}\right) * Exp(BCwater_{[ALLC]} * (GDPPOP_{[ALLC]} - GDPPOP\ dly_{[ALLC]})) * (PGwithdrawl\ dly_{[ALLC]} - FLRwater_{[ALLC]})$$

Where :

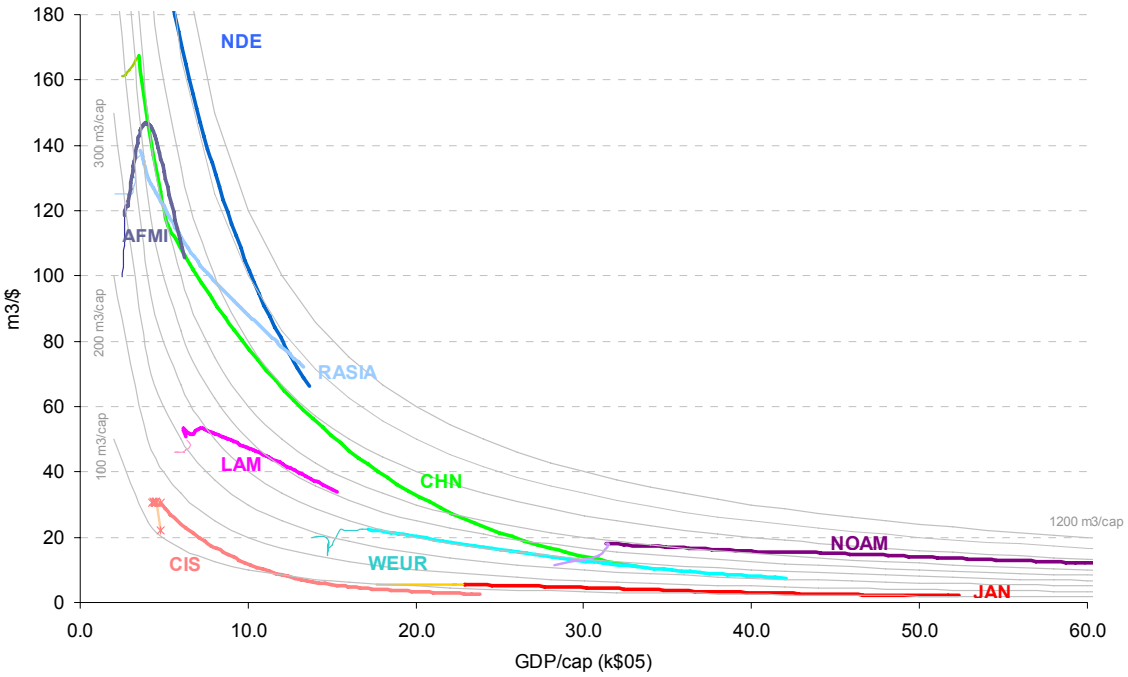
- $PGwithdrawl_{[ALLC]}$ and $PGwithdrawl\ dly_{[ALLC]}$. Intensity water consumption per unit of GDP and the GDP per capita in time t and t-1.
- $GDPPOP_{[ALLC]}$ and $GDPPOP\ dly_{[ALLC]}$ are Gross domestic production per capita in time t and t-1.
- ACwater and BCwater are elasticities
- $FLRwater_{[ALLC]}$ – Floor of water intensity consumption.

Then total water withdrawl is calculated :

$Withdrawl_{[ALLC]} = PGwithdrawl_{[ALLC]} * GDP_{[ALLC]}$

The calibration of the future water withdrawals has been done using the work of Alcamo & ali (2000). Done with waterGap model. A better coordination with the Kassel team will be of great help for further improvement of the results.

Figure 9 : Water intensity use in different regions of the world (1995-2100)



For taking into account the impact of climate change into water requirements, PGwithdrawl is corrected by the change of precipitations and average temperature.

Once the total water withdraw is calculated, this amount is spread into 4 types of supply : Surface, underground, treated and desalinated water. Then electricity needs for water withdrawal are calculated taking into account technical electrical consumption coefficients per water unity.

5.2. Results

This paper presents a first attempt for prospecting total water withdrawals at country level up to 2100 and connecting them with the impact of the climate change. The following figure show the projected World and EU27 total water withdrawal with and without climate change up to 2100. Little impact on water withdraws for the first half of the century and an impact of around 8% for EU27 and 10% for the whole world at the end of the period (Figure).

In terms of the per capita withdrawal, currently EU27 is well over the world average. It converges towards world average during 2020-2050. After that, EU27 per capita withdrawal stabilise and even increase slightly at the end of the period remaining at more than 500 m3/cap which is well higher the world average (~400 m3/cap). The right graph shows that other developed countries, although improves the withdrawal intensity, maintains their higher level of per capita withdrawal compared to developing countries (Figure).

Figure 5 : World and EU27 total water withdrawal with and without climate change up to 2100

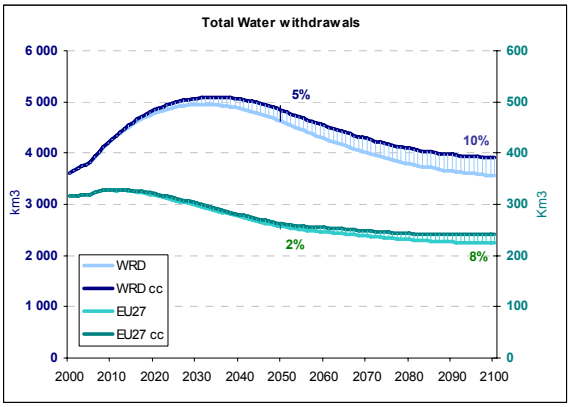
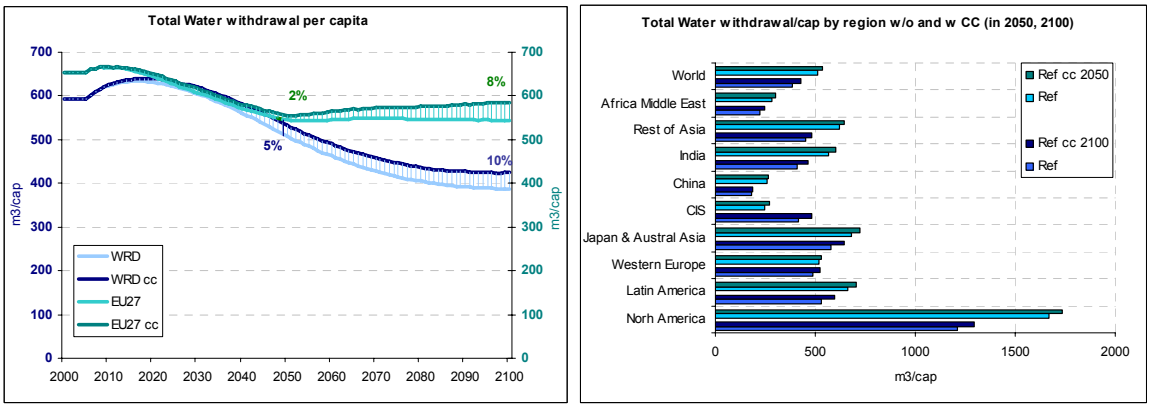
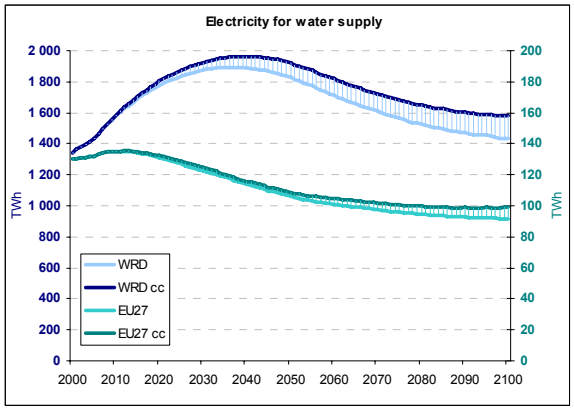


Figure 6 : World and EU27 total water withdrawal per capita with and without climate change up to 2100



Concerning the electricity consumption its pattern follows similar trend as water withdrawal. This situation can be explained by the fact that technological progress in technologies of pumping, desalinisation may be compensated by more deepen underground sources or farther distances. Furthermore, in developing countries are used some other energy sources for water withdrawals that are not counted here.

Figure 7 : World and EU27 electricity consumption for total water withdrawal with and without climate change up to 2100



Currently electricity consumption for water withdrawal represents around 4-6% of total consumption, at the end of the period this share will be less than 2%.

6. Conclusions

The paper outlines a model based approach for analyzing possible effects of global change on energy systems at a country level. Evidently the overview on effects of the climate change in energy sector requires better information. Many uncertainties, including the potential for unexpected and dramatic changes, resulting from climate change threatening the energy supply, call for further research for making the results available and credible to utility planners and policy makers. It is necessary to keep in mind too, the limits of modelling either with POLES model as with IMAGE/TIMER model which are inherently uncertain.

The results, though preliminary, suggest that expected changes in average temperature rising, in precipitation amounts and hydrological regimes need to be accounted for future prospects, adaptation strategies on energy and forthcoming electricity-water tradeoffs in country level. The integration of POLES model with climate and hydrologic models is still very rough. Better integration needs to be done with other climate and hydrological models and many improvements are necessary, as, better representation of the relationship between changes in precipitations, average temperature and water demand; introduction of the competition between different technologies for desalinated water or detail water withdrawals by sector.

7. References

Alcamo Joseph, Döll Petra, Henrichs Thomas, Lehner Bernhard (2001), “EuroWasser: An integrated assessment of climate change impacts on Europe’s water resources“, Center for Environmental Systems Research University of Kassel, p. 18.

Alcamo Joseph, Henrichs Thomas, Rösch Thomas (2000), “World water in 2025 : global modelling and Scenario Analysis fort he World Commission on Water for 21st Century, Center for environmental Systems research, Kassel University, p 49.

Arnell, N (1996), “Global Warming, River Flows and Water Resources“, J. Wiley & Sons Ltd, pp. 25-60, 151-200.

Climate Change Science Program (2008) “Effects of Climate Change on Energy Production and Use in the United States”, p. 96

DOE (2006), “Energy demands on water resources” report to congress on the interdependence of energy and water”, p. 80

Dupont Gaëlle, (2009), “Eau et énergie ne peuvent pas se passer l’une de l’autre”, Le Monde Dimanche 29 - Lundi 30 mars 2009

Durmayaz,n,y Ahmet and Sogut Oguz Salim, (2006), “Influence of cooling water temperature on the efficiency of a pressurized-water reactor nuclear-power plant”, International Journal of Energy Research 2006; 30:799–810, Published online 10 April 2006 in Wiley InterScience (www.interscience.wiley.com).

EEA, (2008). Impacts of Europe's changing climate - 2008 indicator-based assessment. EEA Report No 4/2008.

Goldstein R (2003) « A Survey of Water Use and Sustainability in the United States With a Focus on Power Generation. Topical Report, p. 86.

Goossens X., Bonnet J.F., (2001), “Etude de la matrice des interactions eau-energie », Commissariat Général du Plan, p.36.

Harrison G.P. and Whittington H.W., “Vulnerability of hydropower projects to climate change“, IEE Proc. Generation, Transmission & Distribution, 149 (3), May 2002, pp. 249-255.

IIMI Atsushi, (2007) “Estimating Global Climate Change Impacts on Hydropower Projects: Applications in India, Sri Lanka and Vietnam” The World Bank, Sustainable Development Network Finance, Economics, and Urban Development Department, p. 40. Policy Research Working Paper 4344

IPCC, (2007). IPCC report, Climate Change Impacts, Adaptation and Vulnerability, April 2007.

Isaac Morna and Van Vuuren Detlef, (2009) “Modeling global residential sector energy use for heating and air conditioning in the context of climate Change” Energy Policy 2009.

Labandeira, X., J.M. Labeaga and M. Rodríguez (2006): “A residential energy demand system for Spain”, Energy Journal, 27, pp. 87-111.

Labeaga, J. M. and López, A. (1997): “A study of petrol consumption using Spanish panel data”, Applied Economics, 29, pp. 795-802.

Lehner, B.; Czisch, G.; Vassolo, S. (2005): The impact of global change on the hydropower potential of Europe: a model-based analysis. In: Energy Policy, 33 (7), pp. 839-855.

O. Mohseni and H. G. Stefan, (1999) “Stream temperature/air temperature relationship: a physical interpretation” Journal of Hydrology, Volume 218, Issues 3-4, Pages 128-141.

Sovacool Benjamin K., Sovacool Kelly E. (2009), “Identifying future electricity–water tradeoffs in the United States” Energy Policy 37 (2009) 2763–2773.

Thivet G., (2008) « Eau/Energie et changement climatique en Méditerranée, In : Plan Bleu, changement climatique et Energie en Méditerranée », p. 530-552.

U.S. Climate Change Science Program, (2008) “Effects of Climate Change on Energy Production and Use in the United States”, p. 96.

WEC (2007), Survey of Energy Resources : Hydropower” p. 271-313”.

Wilbanks J. Th. & alii (2008) “Effects of climate change production and use in the United States”, CCSP, p. 74.

Zhelezko Yu. S.,1 V. A. Kostyushko, S. V. Krylov, E. P. Nikiforov, O. V. Savchenko,1 L. V. Timashova, and E. A. Solomonik, (2004) “Power Losses in Electrical Nentworks depending on weather conditions” Power Technology and Engineering Vol. 39, No. 1, 2005, Translated from Élektricheskie Stantsii, No. 11, pp. 42 – 48.

McNeil M.A., Letschert V.E., (2007), Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector, ECEE 2007 Summer Study, 12 p.