Climate Change and Vulnerabilities of the European Energy Balance

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ABSTRACT

Energy consumption induces climate change but at the same time modifications in climate impact the energy sector both in terms of supply capacity and shift in energy demand. Different regions will be affected in different ways and this paper aims at analysing the issue at the European level. Usually rising sea levels, extremes of weather and an increase in the frequency of droughts and floods are indicated to play havoc with the world's energy systems but they can be hardly estimated and this study will be limited to the effects of the increase in average temperature. Tipping points are also taken out of any quantitative assessment. Structure of the EU energy budget is presented, shifts in energy demand, vulnerabilities of supply and risks for energy infrastructure are discussed in order to eventually provide figures of possible further threats to the continental energy security.

KEYWORDS

Energy security, Climate change, European energy budget, Heating degree days, Cooling degree days, Adaptation, Energy supply, Energy demand.

INTRODUCTION

The relation between energy and climate change is usually debated in terms of how emissions from energy consumption induces alterations in the planet’s equilibrium. Indeed, there also exists the issue of how modification of climate impacts the energy sector both in terms of supply capacity and shift in consumption trends.

Assessment of this relation is challenging because reliable forecasts of future climate meet with intrinsic difficulties. First of all, the low predictability of climate as a whole [1] affects the capabilities of making guesses in specific sectors like energy. Second, all forecasts are made under the assumption, reasonable but not certain, that no tipping points [2] will be trespassed. Finally, a shared view among the scholars is that climate will show a double face: the mean, whose effects will be related to the increase of the mean temperature, and the extreme, whose effects come from the increase in frequency and intensity of extreme events. While effects from the increase of the mean temperature are forecasted with a certain degree of confidence, those from extremes are definitely more difficult to predict. Several studies have been carried out on vulnerabilities of energy supply and new trends in consumption both at global [3] and regional [4] level and an extensive US National Climate Assessment [5] has been carried out to specifically address the issue. Nevertheless, because the exact extension of climate change is still indefinite, its effect on the energy sector remains vague. In fact greater uncertainty is on supply and production, affected by extreme weather events, than on energy demand, driven mainly by the increase in mean temperature. Because of this incertitude, most of the literature [6] provides just lists of qualitative trends rather than quantitative evaluations. This paper aims at making a more detailed analysis at European level of the consequences on the EU 27 energy budget and at investigating the exact extent of a possible energy security issue. The analysis is carried out in a +2 °C scenario seen acceptable at the 2010 UNFCCC Cancun Conference even if a recent study suggests this could be accompanied by a significantly changed climate from today, for example in terms of precipitation [7]. In this study will be taken into account only direct effects on energy systems from increase of temperature while indirect effects, like those coming from changes in ecosystems, will be taken out.

STRUCTURE OF EU ENERGY BALANCE

The issue of the energy security, i.e. a possible imbalance between supply and demand, may occur at different time and spatial scales. In this study the focus will be at the level of the annual energy balance. Table 1 shows a condensed version of the EU 27 energy balance for the year 2010 [8] and Figure 1 provides a pictorial view of the same information. The way it is organised is similar to the usual energy balance at national level and contains three sections:

- Supply of primary energy, made by adding up flows of energy entering the continental territory (production and imports) and subtracting flows of energy made unavailable for continental consumption (exports, international bunkers, etc.);
- Transformation + energy industry use + losses, which covers those activities that transform the original primary (and sometimes secondary) commodity into a form which is better suited for specific uses and ready for the final consumption;
- Final energy consumption, obtained by summing up energy spent in industry, residential, services, public administration, transport and so on.

It is worth noting that from 1,759 Mtoe of primary energy, only 1,152 Mtoe become available for final consumption.

The structure could be seen as a matrix whose elements are supply, transformation and consumption vs source types. Climate change impacts each element of the matrix forcing energy needs to evolve. The result will be a new matrix with possible gaps between supply and demand and a potential energy security issues.

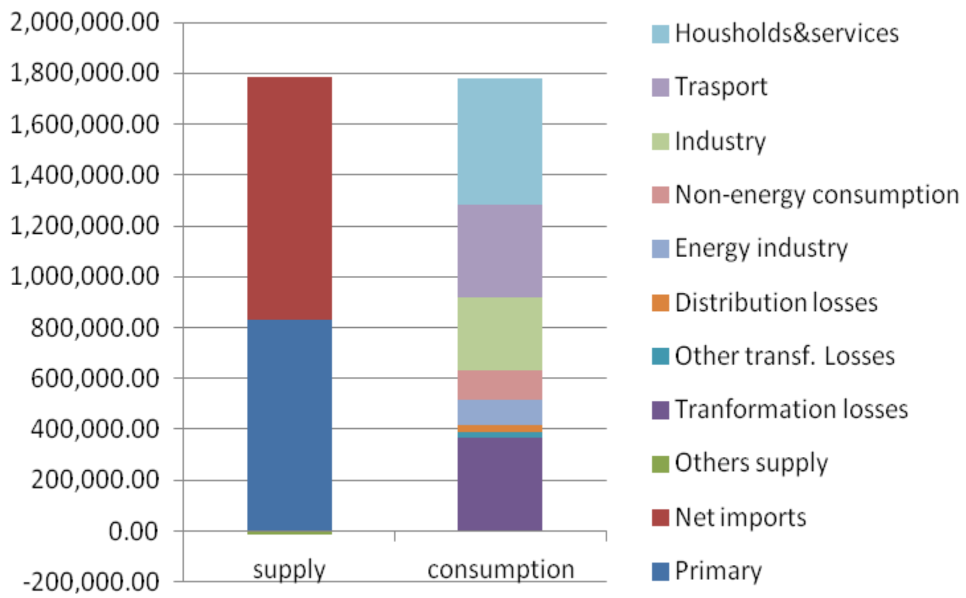

Figure 1. Pictorial view of the EU 27 energy balance year 2010 (Elaboration of Eurostat data)

Table 1. A condensed version of EU 27 energy balance year 2010 (Elaboration of Eurostat data)

EU-27 Year: 2010 1,000 toe	Total all products	All coal	Crude oil and NGL	Feed stocks	Total pet. products	Natural gas	Derived gas	Nuclear heat	Total renew. energy	Other fuels	Derived heat	Electrical energy
Gross inland consumption	1,759,390	2,793.75	6,202.42	11,175	-13,939	441,899	67	236,563	172,326	3,748	-2	299
Primary production	831,105	162,964	94,360	2,997		156,190		236,563	166,851	3,747		
Import-export	951,806											
Other supply	-14,497											
Transformation input	1,400,973	262,176	613,852	52,015	22,366	148,903	8,625	236,563	47,431	1,418	580	165
Transformation output	1,013,230	33,776			655,097		20,730		57		63,562	238,686
Exchanges and transfers. returns	9,444	0	-2,347	40,179	-28,333				-46,432			46,376
Consumption of the energy branch	87,887	880	1		38,825	14,616	3,675		301	0	5,156	24,310
Distribution losses	27,716	45	6		21	4,228	883		25	1	4,494	18,011
Available for final consumption	1,265,488	0	4,036	-661	551,613	274,152	7,614	0	78,194	2,328	53,330	242,876
Final non-energy consumption	114,792	50,046	2,424		97,902	13,146	0		0			
Final energy consumption	1,152,503	55	2,113		454,953	261,170	7,611		78,220	2,328	53,292	242,660
Industry	289,621	48,768	2,113		32,871	84,219	7,553		21,088	2,321	15,457	88,283
Transport	365,117	0	0		343,509	2,435	0		13,328			5,833
Other sectors	497,765	0	0		78,574	174,516	58		43,803	7	37,835	148,544
Households	307,823	13,596	0		42,789	119,334	22		39,750	0	22,661	72,295
Services	152,059	10,461	0		19,472	47,298	36		1,950	7	10,054	71,280
Agriculture/ Forestry	25,068	1,677	0		13,759	3,698	0		1,826	0	290	4,106
Fishing	886	1,388	0		823	1	0		36	0	0	25

SHIFTS IN ENERGY DEMAND

Comprehensive lists of general trends in energy demand driven by climate changes are available in the literature [5]. Certain areas which are expected to play a major role are listed in Table 2.

Table 2. Major driver and trends of changes in energy consumption

Driver	Demand decrease	Demand increase	Sector in energy statistics	Fuel/carrier	Correction factor
Higher mean temperature	Space heating		Residential	Natural gas	f = f(HDD)
		Space cooling	Residential	Electricity	f = f(CDD)
Peak temperature in summer/heat island effects		Electricity peak for space cooling			Local/fine modelling needed
Draught/water scarcity		Irrigation	Agriculture	Electricity	Local/fine modelling needed

Climate change could trigger several drivers of modification. First is the higher mean temperature in itself. Breakdown of EU 27 energy consumption shows that industry, transport and residential sectors take about 90% of the share (see Figure 2). Literature and simulations predict that consumption for transport and industry will be affected little or not at all by increase of temperature. IPCC in 2007 in its Fourth Assessment Report states that: "…*Climate-change vulnerabilities of industry, settlement and society are mainly related to extreme weather events rather than to gradual climate change (very high confidence)…*" [9] and again in 2011: "…*Although the energy, industry, and transportation sectors are of great economic importance, the climate sensitivity of most activities is low relative to that of agriculture and natural ecosystems, while the capacity for autonomous adaptation is high, as long as climate change takes place gradually* [10].

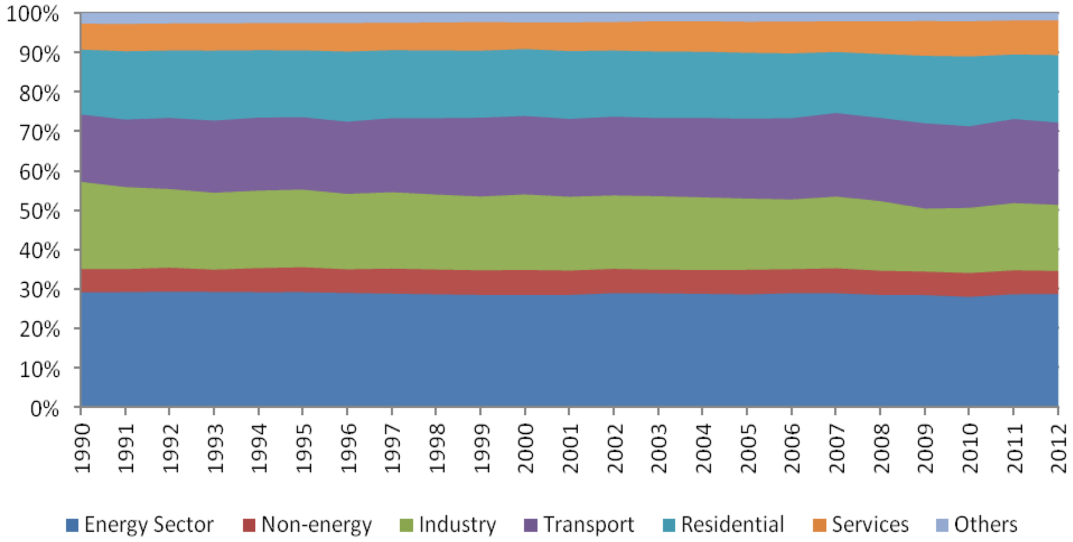

Figure 2. Breakdown of EU 28 energy consumption years 1990-2012 (Elaboration of Eurostat data)

Data on European energy consumption are in agreement with these statements. Figure 3 shows Heating Degree Days (HDD) and energy consumption for industry, transportation and residential from 1990 to 2012 in EU 27. Data are taken from Eurostat database.

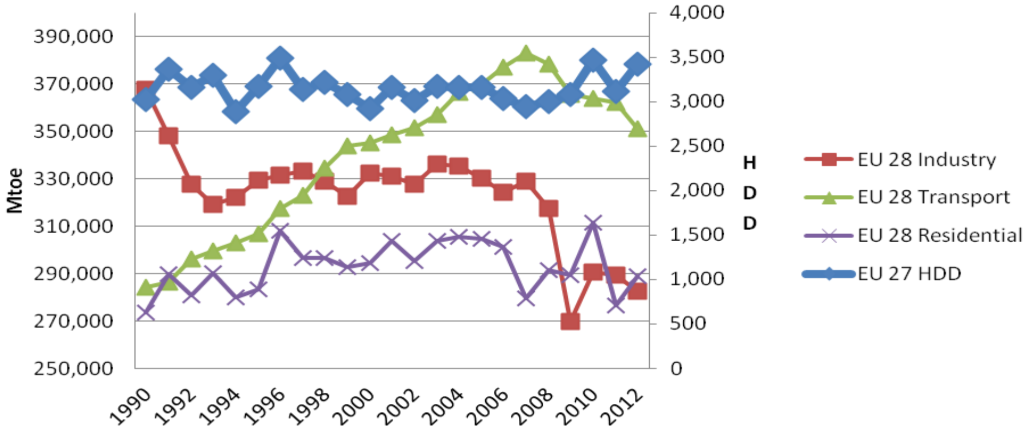

Figure 3. Heating Degree Days (HDD) vs. energy consumption in industry, transportation and residential (households + services) in EU 27, years 1990-2012 (Elaboration of Eurostat data)

At a glance, it appears that industry and transportation are quite independent from HDD while residential sector shows a different behaviour. In fact, calculations give a correlation factor between HDD and industry consumption or HDD vs. transportation is equal to -0.20 while a significant 0.45 between HDD and residential indicates a much stronger relation between climate and consumption in residential sector.

Because industry and transportation sectors represent about 2/3 of energy demand, it appears that the same ratio could be considered climate independent (see Figure 4) and does not entail, from this point of view, issues of energy security. In fact, a warmer world will demand less space heating and more energy for space cooling in summer. Usually these shifts are expressed in HDD and CDD (Cooling Degree Days). In EU-27 in the period 1980-2009 the number of HDD has decreased by 13% [11], yet with substantial inter-annual variation. The pattern shows that the decrease has not been homogeneous across Europe and the absolute decrease has been largest in the cool regions in northern Europe where heating demand is highest. Other studies calculate a 10% reduction of HDD for most locations in Europe [12] under the assumption of a temperature increase of 1 K in winter. In this paper the effect on energy demand for heating is assumed to be in linear relation with HDD and expressed as [13]

$$(\text{Residential \& Services heating})_{acc} = (\text{Residential \& Services heating})_{bcc} \times \text{HDD}_{acc} / \text{HDD}_{bcc} \quad (1)$$

Acc and bcc stand for "after" and "before climate change". The exact value for bcc depends on which year is taken as reference, while acc depends on model, year and selected future scenario. The same reasoning applies to CDD that are expected to increase. Several scholars [14] suggest that the worldwide energy demand for cooling will increase not only to face higher summer temperature but also the increase of cooled surface. Because this is going to happen mostly in non OECD countries, will not be considered in this study on European trends.

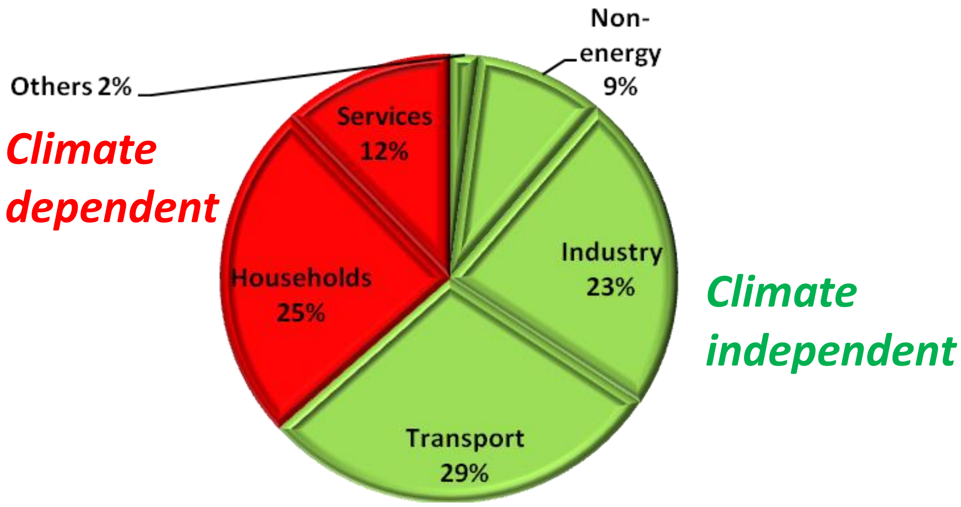

Figure 4. Breakdown of EU27 2010 energy balance in climate sensitive areas (Eurostat data)

Because the EU27 buildings use 23% of the primary energy supply [15] and almost 40% of total final energy consumption [16] is for heating, a possible decrease from 10 to 20% of HDD will imply a saving from 4 to 8% of total energy consumption.

This must be compared with the effect of increase in CDD to have a figure of the net saving. It's useful to remind that surface cooling is done through electric devices and electricity accounts for about 20% of the total EU 27 energy consumption. A breakdown of electricity consumption (see Figure 5) shows that residential + services take together a share of 60% but not more than 5% is used for air conditioning. In Figure 5 this is shown only for services but this applies also to residential [17]. All together the net result is that surface cooling takes about 1% [20% (electricity share of total energy consumption) × 60% (services-residential share) × 5% (air conditioning share)] of total energy consumption. A 65% (Table 3) increase in CDD could even double this figure but in the overall budget, it appears largely offset by the savings from the reduction of HDD. Beside the increase of the average temperature, climate models predict that local peaks in summer temperatures will be much more frequent and more pronounced in absolute value. This does not entail shortage of energy *per se* but, because the total installed power is tailored on peaks of electricity demand, more robust interconnections in and among regions and possible re-sizing of power plant parks will be needed.

Agriculture appears in Table 2 since water scarcity could exacerbate the need of energy for irrigation and increase the total demand in critical summers. In fact, climatic variables, such as temperature and precipitation, are essential inputs to agricultural production and different combinations and seasonal patterns have a direct consequence on yields. That said, agriculture accounts only for about 1% (see Table 1) of total electricity consumption.

In summary, only households and services consumption appear to be climate sensitive producing a combined effect, in a +2 °C scenario, of a possible reduction of 6% in total energy consumption.

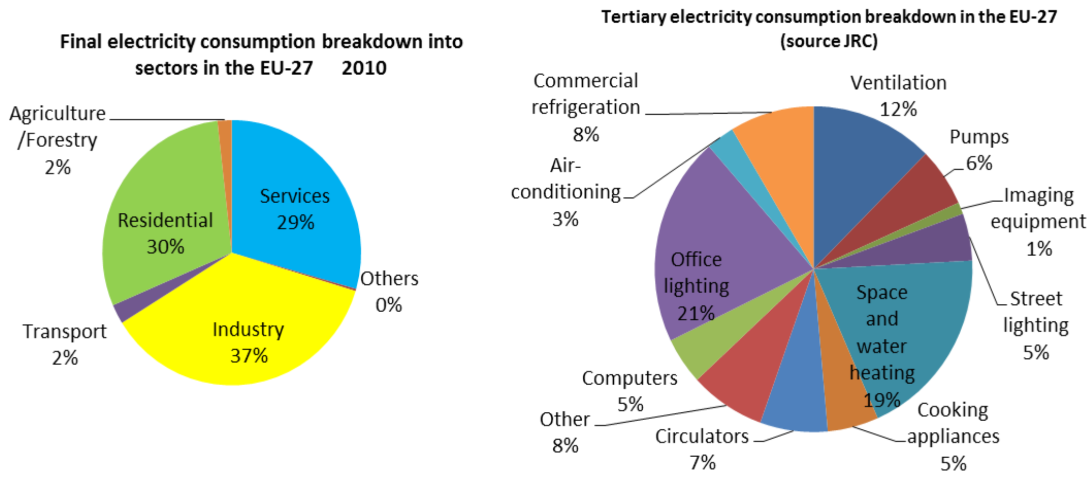

Figure 5. Breakdown of electricity consumption in EU 27, year 2010 (JRC elaboration of Eurostat data)

VULNERABILITIES IN ENERGY SUPPLY

The future of energy supply is much more difficult to predict. Table 4 summarises how this sector could be hit by climate change. It appears that supply based on fossils could be affected in several ways. First in the table are extreme weather events. Type, frequency and intensity of these extremes vary region by region [18] and this raises concerns about energy infrastructures which were built to meet climate conditions of the past and there is no reason to believe that they will meet future conditions. However, there are claims that off-shore gas/oil platforms already today usually operate within extreme weather conditions [19]. Whatever the real resilience is, the only answer to extremes will be adaptation.

This is different from water scarcity, second in the table and most likely a more compelling concern, where proactive initiatives can be put in place in advance. Today, United States and Europe produce 91% and 78% of their total electricity by thermoelectric (nuclear and fossil-fuelled) power plants [20], which directly depend for cooling on the availability and temperature of water resources. This makes the supply of electricity vulnerable to the combined impacts of lower summer river flows and higher river water temperatures. In fact, even when cooling water is available, its temperature is expected to rise [20] and plant efficiency to decline. In particular, for 1 °C increase in air temperature, the power output of natural gas-fired combustion turbines (often used for peaking) is estimated to decrease by approximately 0.6% – 0.7% [21]. In the same condition, nuclear power plants, output losses are estimated to be approximately 0.5% [22] [23]. A further difficulty is that electricity generation, in case of drought, goes in fierce competition with agriculture. This is not listed in Table 3 because it does not directly affect the level of energy supply but could occasionally force to stop or reduce plants operation in case agriculture needs have a higher priority compared with energy production. In order to simplify our scheme, a 0.5% decrease of efficiency per °C will assumed in all thermo/nuclear power plants.

Table 3. Trends in energy supply driven by climate change

Driver	Supply decrease	Supply increase	Sector in energy statistics	Fuel/carrier
Extreme weather events	Oil and gas exploration and production		Oil and gas extraction	Oil and gas
	Disruptions of infrastructures (transport, transmission,...)		All	All
Summer peak temperature/heat island effects/water scarcity/Draught	Thermal power plants stop/reduced operations and lower effiency		Electricity conversion	Fossils and nuclear
	Biomass reduction		Bio production	Biomass
	Reduction of hydropower generation		Hydropower	Hydro
Sea level rise	Threat to coastal power plants and infrastructures		All	All
Cloud and dust	Reduced solar plant capacity		Renewables production	Electricity
Change in climate geographical pattern	Reduced generation capacity of existing renewables	Local increase	Renewables production	Electricity
Side effects from other countries	Biomass, oil and gas import disruptions		Total primary production	Biomass, oil and gas

The situation with renewables is much patchier. The previously mentioned US draft Climate Assessment contains a table of *Challenges in energy supply* (page 181) [5] and in the column "Solar PV Wind", any quantification of trends is dropped by the following comment: "Impacts projected but not well defined at this time". This sort of difficulty comes as no surprise because estimates of renewables productivity strongly depend on local conditions and therefore detailed knowledge of geographical patterns of future climate are needed before any assessment [4]. Concerns about the productivity of renewables are legitimate but there are two big pros to be taken into account: they are almost all immune from water scarcity and solar power, in particular, is available when it is needed most - during peak demand hours.

Last but not least, vulnerability is fed also by the uncertainty of the supply of imported fuel. Changes in climate could spare some countries and heavily hit others in terms of resource endowment. In the latter case, if the affected country is an exporter, the importer could also experience a shortage of fuel.

Beyond mining and production operations, the effects of peculiar weather conditions could jeopardise the energy supply sector in other ways like the transmission infrastructure. Moreover, electricity outages could have widespread effects as electric powered instrumentation, compression pumps and processing equipment are essential links in the process of creating and moving gas to the end customer. In some instances, even the brief, temporary loss of electric power can put a gas production, processing, compression, or storage facility out of service for long periods of time, especially where weather conditions delay access to those facilities [24]. This is difficult to quantify.

Finally, there is an impact on transmission lines. A 5 °C increase in air temperature could decrease transmission line capacity. Estimation in +5 °C scenario suggest a decrease by 7% – 8% [25] which, for a rough and conservative assessment, could imply a 2% loss per °C on the electrical energy.

NET ENERGY BALANCE

After having analysed the effects of climate change both on energy supply and demand, it is now possible to look at the values for each of the elements in the energy balance and find out how rooted is the concern for possible threats to the energy security in Europe. In order to make the effects on energy balance easier to read, a simplified version of the above energy balance is used and all sources together are collapsed in a single column. Supply area is split in three macro areas: primary production, net import and others. Energy demand is split in: industry, transport and residential + services. The total balance is closed with energy transformation, energy management and non energy use.

Breakdown of effects of climate change on energy sector will be the following:

- Energy supply will not be affected by climate change, extreme weather events apart;
- Transformation will suffer a decrease of efficiency in thermal power plant expressed by:

$$\Delta E_{in} = 0.005 \times \Delta T \times E_{in} \tag{2}$$

E_{in} is amount of energy to be transformed and ΔT is the temperature change;

- Electricity distribution will experience an additional loss of energy expressed by:

$$\Delta E_{el} = 0.02 \times \Delta T \times E_{el} \tag{3}$$

where E_{el} is amount of electricity produced and distributed;

- On the demand side, change in consumption will be driven by change in HDD and CDD:

$$E^{heat}_{acc} = E^{heat}_{bcc} \times \_HDD_{acc} / HDD_{bcc} \tag{4}$$

$$E^{cool}_{acc} = E^{cool}_{bcc} \times \_CDD_{acc} / CDD_{bcc} \tag{5}$$

In a +2 °C scenario, the previous assessment applied to the EU27 2010 energy balance produces the effects listed in table 4. The green cells highlight values unaffected by climate change while the red cells indicate affected values. Overall, a 75 Mtoe reduction in energy consumption improves the overall energy balance by 4%. This means that, in a +2 °C scenario expected to be far from any tipping point, the issue of energy security for Europe will not be exacerbated but possibly alleviated.

Table 4. Modification of EU 27 energy balance as effect of climate change in +2 °C scenario

		Supply bcc	Consumption bcc	Supply acc	Consumption acc
Supply	Primary	831,105.00		831,105.00	
	Net imports[1]	951,806.00		951,806.00	
	Others supply[2]	-14,497.00		-14,497.00	
Energy transformation /distribution	Transformation losses[3]		366,454.00		372,969.04
	Other transf. losses[4]		22,887.00		22,887.00
	Distribution losses		27,716.00		37,263.44
	Energy industry[5]		97,331.00		97,331.00
Non-energy consumption			114,792.00		114,792.00
Final energy consumption	Industry		289,621.00		289,621.00
	Transport		365,117.00		365,117.00
	Households & services		497,765.00		405,564.76
Total		1,768,414.00	1,781,683.00	1,768,414.00	1,705,545.24

[1] Imports-exports
[2] Recovered products + Stock change - Bunkers + Direct use
[3] (Tranf. input - output) (Main act. and autoprod. of thermal power station + nuclear power stations)
[4] Briquetting, Coke-oven, Blast-furnace and District heating plants + Gas works + Refineries
[5] Exchanges and transfers. Returns + Consumption of the energy branch

CONCLUSION AND MAIN FINDINGS

Energy demand and supply are going to be modified in Europe as an effect of climate change and the possible threat to energy security needs to be discussed in advance. Data of EU27 energy balance in 2010 have been analysed and their change in a +2 °C scenario has been discussed. There are significant differences among countries but this study analyses European data as a whole. Quantitative assessments have been made at the level of first order calculation, both for the sake of simplicity and because the great incertitude on future scenarios could make a supposed higher resolution meaningless. The main findings are:

- More than 60% (industry + transport) of European energy consumption is today (2010) climate independent;
- The remaining 40% of consumption is about households and services. Around 70% of this share goes in heating while less than 5% goes in cooling. Heating and cooling are usually correlated to HDD and CDD which are expected to change in -20% HDD and +65% CDD. The net result will be a reduction of 5% in energy consumption;
- On the supply side, an exact picture is much more difficult to depict but effects are expected to be small if, overall, not zero. Mining and extraction are expected to be climate independent. The only area which could be affected is electricity production and distribution. In fact higher temperature means lower efficiency of thermal power plants and increase in distribution losses. Combination of the two effects results, ceteris paribus, in a decrease of 1-2% in energy availability but the energy sector could easily cope with this request of resilience.

All previous assessments are made without taking into account consequences of extreme weather events, which are expected to increase in intensity and frequency but whose effects on energy sector can hardly be estimated. Tipping points are also taken out of any quantitative assessment.

The overall picture is that climate change in Europe is not going to pose a dramatic challenge to energy security. In fact, the large share of fuel import, more than 70%, will remain the biggest threat for decades to come.

Previous conclusions do not want to underestimate the importance of proactive actions to make the energy sector better prepared to adapt to climate changes and top priority should be given to improving the power sector's resilience. Back-up power generation, additional peak power capacity, distributed generation, interconnections among electric grids and portable generators to critical facilities for possible outages are examples of needed actions. Integration among parts is needed in order to maximise efficiency and flexibility but extreme weather suggests that making each part able to survive any possible disruption is also essential. The World Energy Council (WEC), recently compiled a study along with Cambridge University and the European Climate Foundation, urging generators to examine their vulnerability to climate change, saying that with suitable adaptations the worst of the problems could be avoided. That said, given the usual large incertitude on energy forecast aggravated by the intrinsic limits of climate models, a part of 'play it by the ear' will be unavoidable.

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