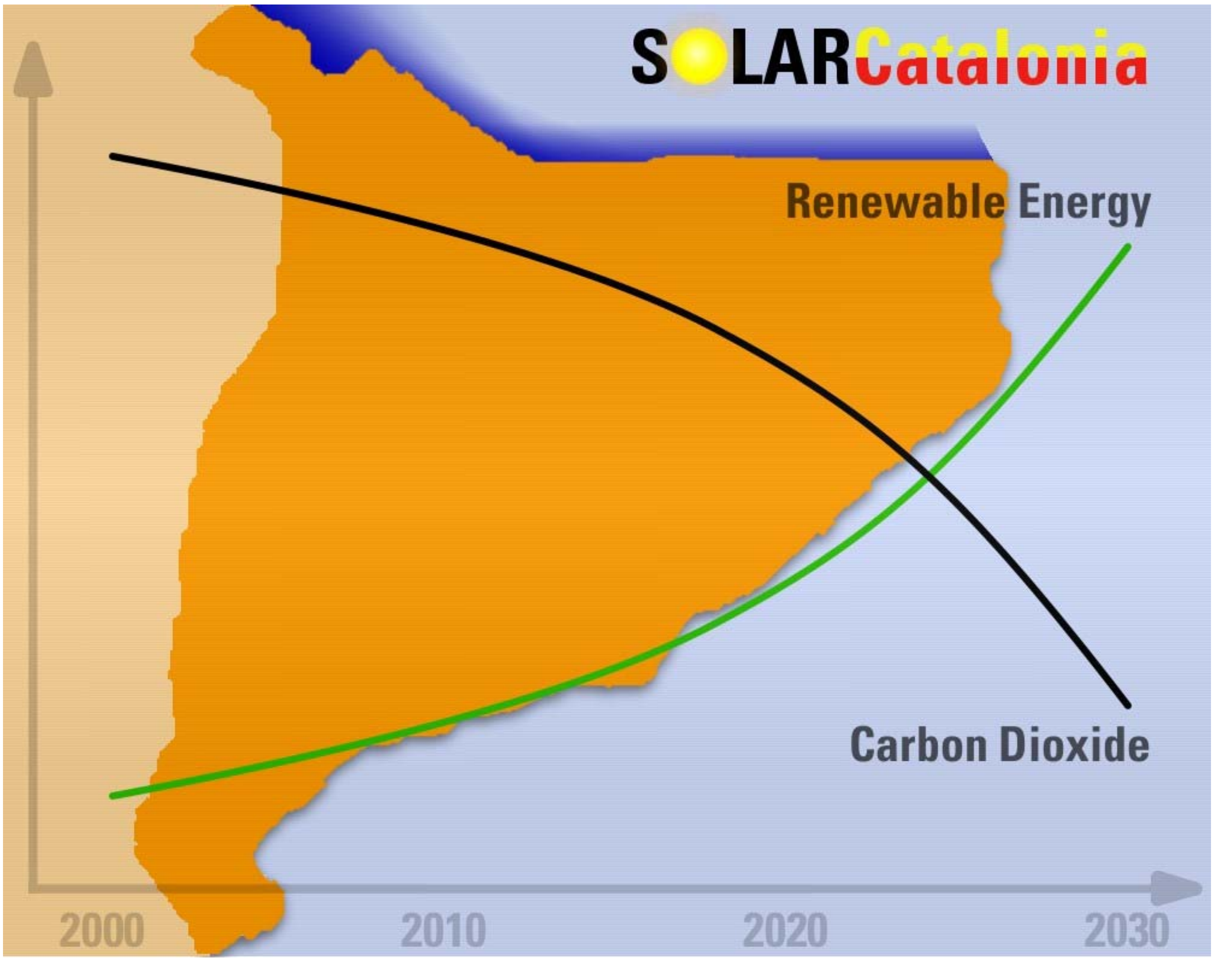
Solar Catalonia

A Pathway to a 100% Renewable Energy System for Catalonia



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Introduction

At the latest since the currently released IPCC climate study there cannot be any legitimate doubt that the ongoing climate change is man-made. The possible magnitude of climate change is set to reach levels that threaten our economies, the stability of ecosystems and, hence, a sustainable development. Lately Nicholas Stern, former chief economist of the World Bank, draw the focus on the (previously unnoted) economic aspects of climate change. According to Stern's analysis climate change could cause a decrease of the global GDP by at least 10%, and - in the worst case - even by 20%.[1]

A rise in global average temperature up to 6° C – compared to the pre-industrial level – is within the realms of possibility if the present trend in greenhouse gas emissions continues.[2] This is far above the increase of 2° C, which often is said to be the "red-line" that must not be crossed in order to keep the consequences of climate change on a scale that can be managed. To avoid the increase in average global temperature to exceed this limit, the atmospheric concentration of greenhouse gases (GHG) must be stabilized at a level of about 420 ppm (parts per million) of CO_2 equivalents (CO_2 eq.) on a long term[3].

This stabilization can only be achieved if global GHG emissions are reduced to less than the half by the middle of this century. As today's developed countries are the predominant contributors to global GHG emissions, it must be their commitment to make first moves towards a clean energy supply[4] and to reduce their GHG emission by 80% within this time[5]. Developed countries, among them the Member States of the European Union, must provide intermediate targets to keep this process revisable, transparent and convincing to others. Thus developed countries must set a binding target to reduce their emissions by 30% by 2020[6].

The serious consequences of using fossil fuels and the risks of nuclear energy show us that the use of these technologies must be discontinued. With regard to fusion, this technology has so far not functioned and would also involve the production of radioactive waste if it did.

Beneath the benefits of avoiding greenhouse gas and other pollutant's emissions and risks imposed by nuclear technologies, a sustainable energy system will save scarce resources (e.g. oil, which will be needed by future generations for chemical, medical and other purposes) and it will not have to temper with increasing prices for fossil or nuclear fuels.

A sustainable energy supply must combine renewable sources and energy efficient technologies, as it will not longer be possible to live on "energy-credit" by using fossil fuels

[1] Stern 2006, Summary of conclusion, S. vi
[2] IPCC 2001
[3] Quoted from the IPCC's Fourth Assessment Report, Working Group III, by Financial Times Deutschland, via internet: http://www.ftd.de/forschung_bildung/forschung/164397.html
[4] developed nations produce 80% of the world total greenhouse gas emissions from fossil fuels.
[5] Cf. UBA 2005a, p. 15
[6] Percental GHG reductions in relation to 1900 levels

earth produced during thousands of years. Instead, a sustainable energy supply is restricted by the power sun, earth's core and gravitation deliver and the areas where renewable technologies can be installed. This does not mean that there will be a lack of energy in general, but it forces us to use energy wisely and efficient.

The objective of initiating this study is to show that a Catalonia is able to supply its own need for energy from renewable sources. Giving such a fact-based vision of a future energy supply is very important to influence the discussion about the change from fossil/nuclear energy sources towards a sustainable energy system, especially, as the ongoing discussion regarding the possibilities of renewable energy and efficient design has been negatively influenced by a lack of facts about the availability and potential of these technologies.

Different studies already analysed the feasibility to supply different regions exclusively by renewable energy sources. The "Energy Rich Japan" study, for example, showed how to supply Japan by domestic renewable energy sources[7]. Other studies, e.g. "Long Term Integration of Renewables into the European Energy System"[8] and "Sustainable Energy Supply Against the Background of Globalisation and Liberalisation"[9] demonstrated this possibility on the European and Germany respectively.

The project's results will help to move towards a fossil fuel- and nuclear energy free system. Setting out a framework for a highly renewable electricity supply (up to 100%) also provides the inspiration to make moves in the direction of a sustainable future.

The wind-energy boom of the last few years, making Spain the actual front-runner in the wind-energy market, is a good example for "best-practice" in renewable energy support. Now it is Catalonia's chance to go one step further by proving that sustainable development, based on renewable energies, and economic prosperity can come along.

The goal of the project is to show that a sustainable renewable and efficient energy system is able to supply Catalonia's current needs. This entails that the study does not consider any major changes in lifestyle and that the reductions in energy demand does neither cause any changes in living standard, nor do they assume any demographic changes. Consequently there are no assumptions regarding the future economic development in terms of Gross Domestic Product or the like.

The study is focused on Catalonia's actual electricity energy demand - and how it can be reduced - and the design of an energy supply system, which is able to cover the electricity demand on base of renewable energy technologies.

The study delivers basic information on energy demand, introductory scenarios for the further development of renewables, a simplified simulation of the Catalonian electricity supply

[7] "Energy Rich Japan", Study commissioned by Greenpeace International and Greenpeace Japan, ISuSI; 2003

[8] "Long Term Integration of Renewable Energy Sources into the European Energy System", LTI-Research Group, Available at Physica-Verlag; ISBN: 3-7908-1104-1; 1998

[9] "Sustainable Energy Supply Against the Background of Globalisation and Liberalisation", Enquete Commission of the German Parliament; 2002

system with the SimREN simulation software[10] and policy measures to deliver best support for a sustainable energy supply.

[10] The SimREN software was especially designed to simulated electricity supply systems with a high share of renewable energy technologies (up to 100%).

Summary

The objective of initiating this study is to show that a Catalonia is able to supply its own need for energy from renewable sources. Giving such a fact-based vision of a future energy supply is very important to influence the discussion about the change from fossil/nuclear energy sources towards a sustainable energy system, especially, as the ongoing discussion regarding the possibilities of renewable energy and efficient design has been negatively influenced by a lack of facts about the availability and potential of these technologies.

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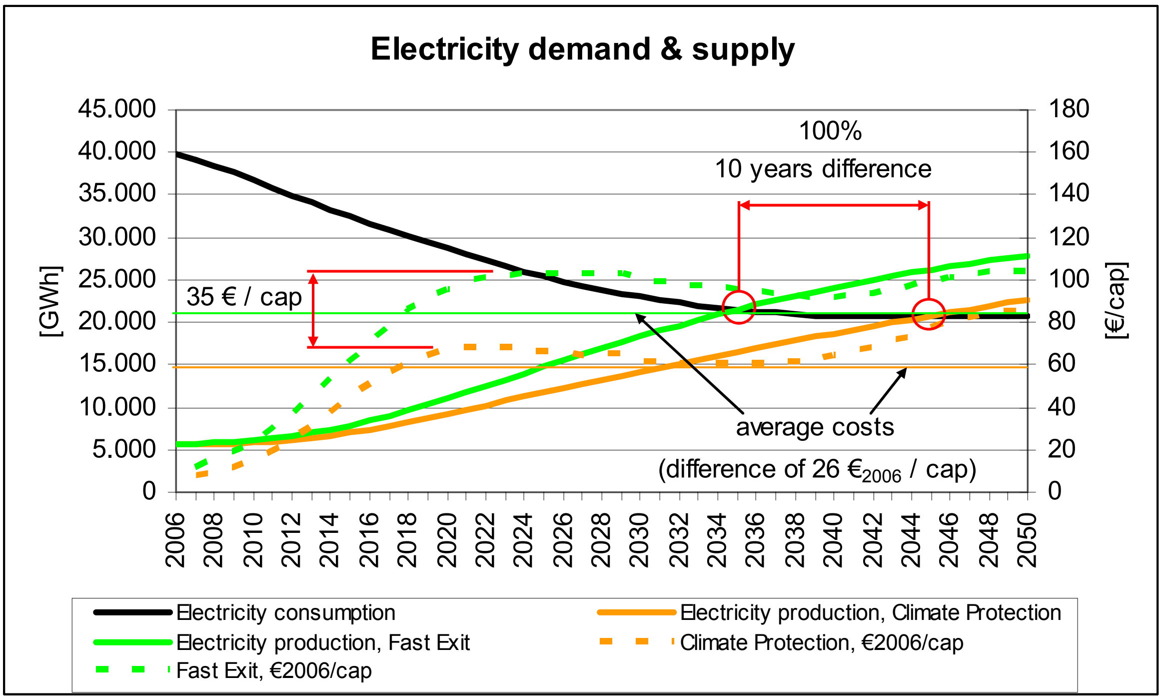
Although Catalonia showed a strong economic growth within the past ten years, Catalonia did not perform well with regard to energy intensity. It is quite clear that energy intensity in the Catalonian economy must be reduced in order to shift to a sustainable energy supply and to make it's own contribution to climate protection. The scenarios within this work highlight a development towards halving electricity intensity in the three most important sectors of electricity consumption until 2050. This, of course, means making great efforts to improve the efficiency of electricity use, but we are convinced that this is feasible from a technological point of view. Further technological development towards more efficient appliances will assist such a development and restructuring our economies and redefining the relationship between energy consumption and wealth may be necessary but, in the end, climate change and it's serious consequences will force us to walk this way. After all one fact is quite clear: we have to start now in order to keep transition smooth and to avoid the most serious consequences of climate change.

Taking the development as proposed here will bring down Catalonia's electricity consumption to the 1993 level until 2025 and to the half of 2003's electricity consumption by 2050. Even with respect to the facts, that further reductions will be harder to achieve the further we step into future and that a certain level of energy intensity will remain, the developments presented here show two remarkable facts: although getting energy intensity down to the half sounds very hard, half of the way solely consist of revoking the increase in energy intensity from 1993 to 2003. The remaining effort in efficiency improvements (compared to the efficiency Catalonia already had in 1993) is not of an extend that should make us doubt that this goal can be achieved.

Both scenarios show the feasibility to achieve a fully renewable supply, one until 2035 (Fast Exit Scenario), the other until 2045. This is not a matter of potentials, but it is a matter of setting and pursuing ambitious goals, encouraging policy and people and – of course – the financial investments Catalonia and it's people are willing to take. The scenarios show that the financial aspect is not that big obstacle that one might expect. With an annual investment into renewable capacities peaking at 104 $€_{2006}$ per inhabitant in the "Fast Exit Scenario" (2050) and 85$€_{2006}$ / cap in the "Climate Protection Scenario", the financial burden to achieve a clean a climate friendly electricity supply in Catalonia is moderate in our point of view; in 2030 investments are 103 €2006 / cap in the "Fast Exit Scenario" and 68 €2006 / cap in the "Climate Protection Scenario" (see Picture 1).



Picture 1: Development of electricity demand and supply in the scenarios

These financial figures are only the peak investments during the whole development considered here. Calculating the average annual payments for the two different scenarios result to 58 $€_{2006}$ per inhabitant and year in the "Climate Protection Scenario" and 84 $€_{2006}$ per inhabitant and year in the "Fast Exit Scenario".

Compared to the Catalonian Gross Domestic Product (181,029 million € in 2005) the annual costs of the scenarios are 0.2 % of the GDP for the "Climate Protection Scenario" and 0.3 % for the "Fast Exit Scenario" on average.

Any energy supply system must guarantee sufficient production and distribution of electricity, heat and fuels to meet the demand for energy at any time throughout the year, usually using different energy conversion technologies. Energy is supplied in the form of electricity, heat or fuels, with heat and fuels having the advantage that both can be stored for later use and can be easily transported. So it is not necessary to consume heat and fuels immediately or directly at the production site. Heat can be stored in thermal reservoirs and distributed via district heating networks. In contrast to heat and fuels, which dissipate with time - thus setting a limit to storage time and distribution distance -, fuels from biomass or hydrogen does not have this limitation in storage time or in transport (depending on the fuel type - solid, liquid or gaseous), but storage losses must be considered too.

The situation is completely different with electricity. The necessity of producing enough electricity, on demand and on time, makes this type of energy the most critical component in an energy supply system. While electrical transport via the public grid is quite unproblematic, storing electricity directly on a large scale is material- and cost- intensive. However, storage in batteries and accumulators can involve the use of toxic substances. Therefore this option is not considered here as it is not appropriate for a sustainable energy supply system. Indirect storage can be used, e.g. pumped hydro-storage systems.

An energy supply system which is based almost completely on renewable sources increases the focus on timely energy provision due to the fluctuating nature of some renewable energy sources, such as solar and wind. Including such fluctuating sources into the public electricity supply means that the power produced by those sources might decrease relatively fast. Of course electricity production from fluctuating sources can be estimated by weather forecasting but a portion of uncertainty still remains. Fortunately, there are other renewable technologies with the ability to deliver energy on demand; hydropower and geothermal power plants give direct access to renewable sources, cogeneration and other energy sources can use fuel from renewable sources (e.g. hydrogen or biomass).

The challenge in designing a highly renewable electricity supply system (up to 100% renewables) is to find the combination where advantages of each renewable source sum up to a functioning and reliable system, while disadvantages are balanced out. Especially in the electrical system the need for reserve capacities, necessary as a back up for fluctuating sources, can be minimised by choosing the right combination of renewable technologies to minimise fluctuations and the introduction of demand management to get a better alignment between production and demand.

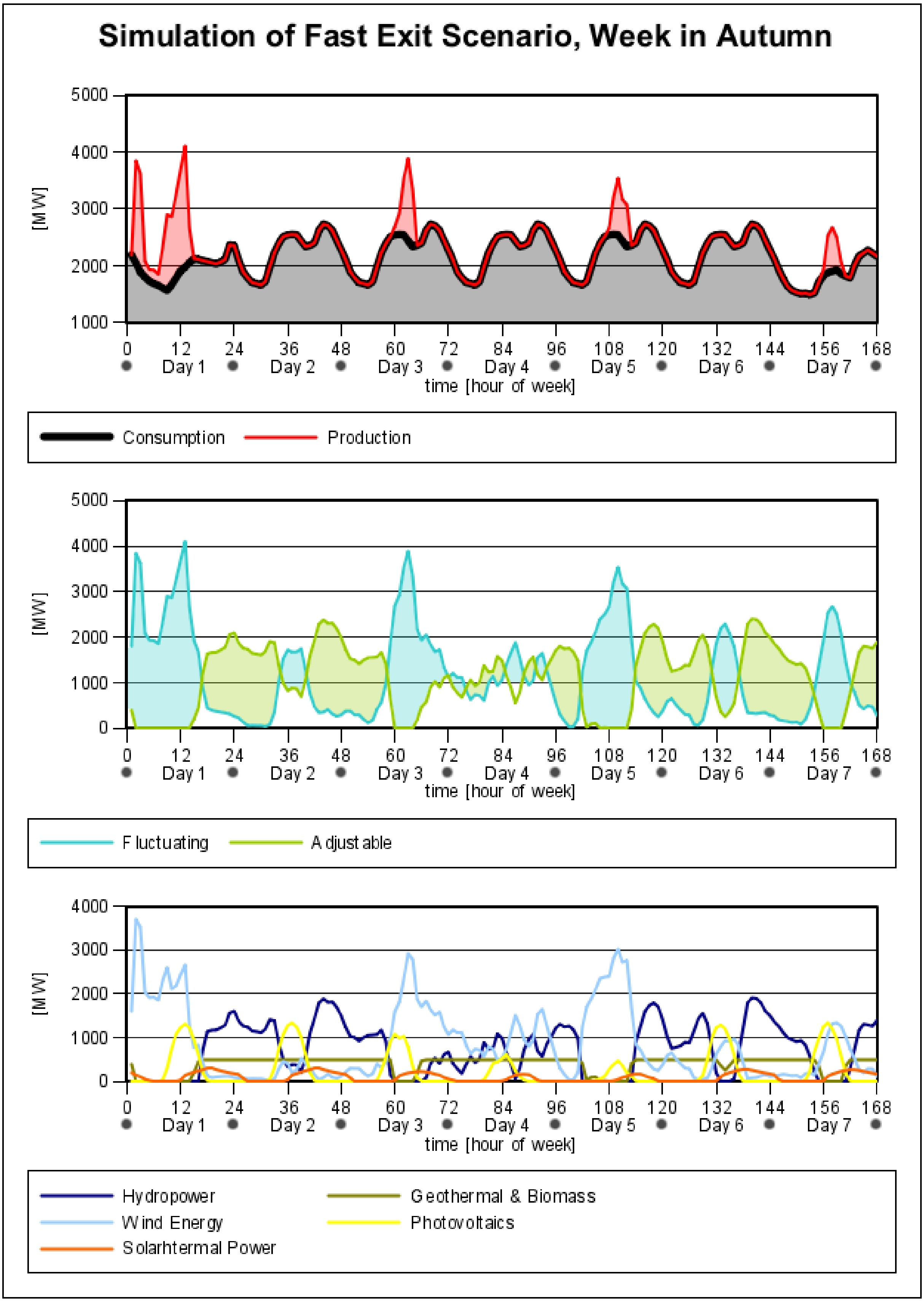
In this study we only studied the dynamical behaviour of the electrical system in the scenario “Fast exit”. This was done without optimising the electrical energy system. This simulation was done for 4 typical weeks (spring, summer, autumn and winter), with typical weather of the year 2006 [MeteoCat; 2006][11]. The optimization of the supply system and the introduction of modern electrical grid management methods (e.g. Demand Management) will be investigated in a later study.

Taking the four simulated weeks as representative for all the four seasons of the year, the supply system according to the “Fast Exit” scenario is capable of supplying all the electricity

[11] [MeteoCat; 2006]: *Servei Meteorològic de Catalunya (*Dades EMA integrades a XEMEC). Department de Medi Ambient i Habitatge

demand in Catalonia. Generally solar- and wind performance are substantially better during spring and summer than they are in autumn and winter. Due to the strong spring and summer performance of fluctuating suppliers (solar and wind) it is often the case that photovoltaics, solar thermal power and wind energy can supply by far more than the total electricity demand.

During the winter half year the adjustable suppliers are predominant in supply, as the decrease in solar radiation appears in conjunction with generally lower wind speeds. Looking at the big picture the climate variation over the year, with strong solar and wind performance during the warm periods over the year, favours a system as described here, as the adjustable suppliers (hydropower, geothermal and biomass) have to contribute most during those times when they can be operated in the best way. While a high utilisation of hydropower coincides with higher precipitation levels, geothermal- and biomass plants can mainly be operated during times with a higher demand for heat, thus giving the opportunity to take advantage of high efficient combined heat and power plants.



Picture 2: Results of the simulation for one week in autumn

Energy Demand Module

Methodology

Electricity demand projection in this study takes a conservative approach, as it strictly relies on historical developments and there are no assumption regarding future energy intensity reduction that have not been observed within the past.

The indices used to describe the historical development and the future projections as well is the electricity consumption per sector in relation to the sector's Gross Domestic Product. This index was chosen as electricity consumption now and in future will be closely related to economic activity, whether this might be in the industrial, the services or the domestic sector

As this study is focused on electricity, only this part of the energy system is analysed in detail.

For most of the projections, namely in the industrial and domestic sector, it is assumed that the pace of efficiency increases , which already has been achieved within the earlier 1990's can be regained up to 2010 and maintained until 2025. In the aftermath the projection given here expect successively decreasing efficiency gains and – lastly- no further reduction after about 2040.

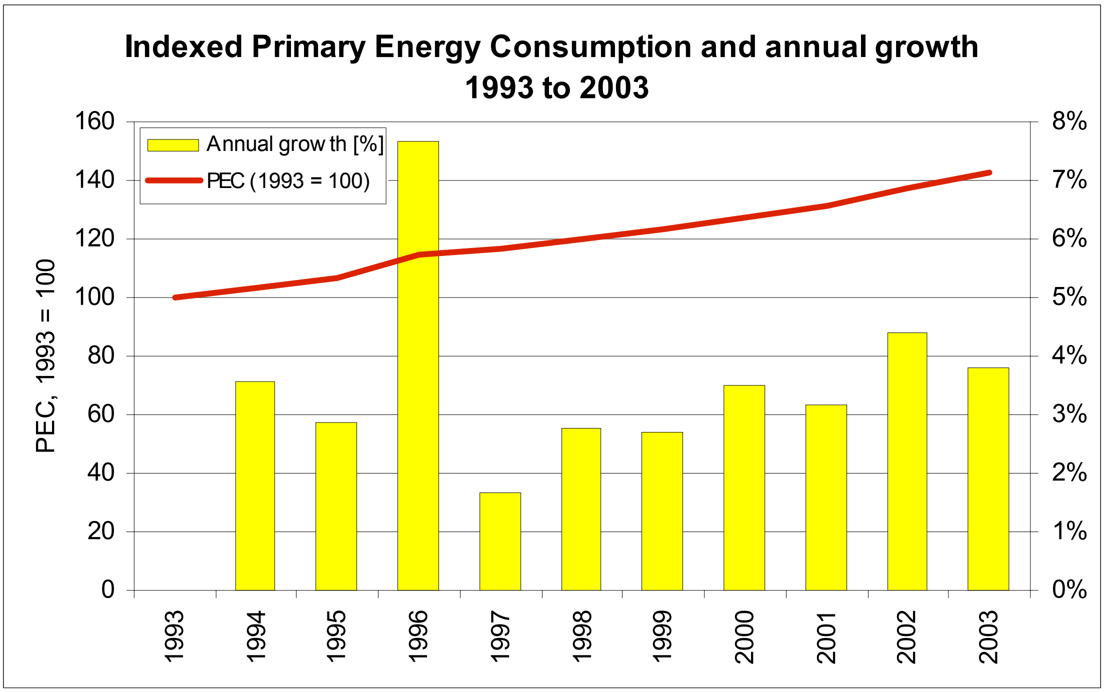
A slightly different assumption is made in the services sector, as in this sector – in contrast to industrial and domestic sector – there was a steady decrease in energy intensity from 1993 to 2003. For this sector the 1993 to 2003 annual average decrease gets extrapolated until 2025. Afterwards the projection considers the same slow down as for both other sectors.

There are no expectations regarding the further development of economy in term of Gross Domestic Product. Consequently the absolute electricity consumption gets extrapolated on base of the Catalonian GDP in 2003.

History of Energy Consumption in Catalonia

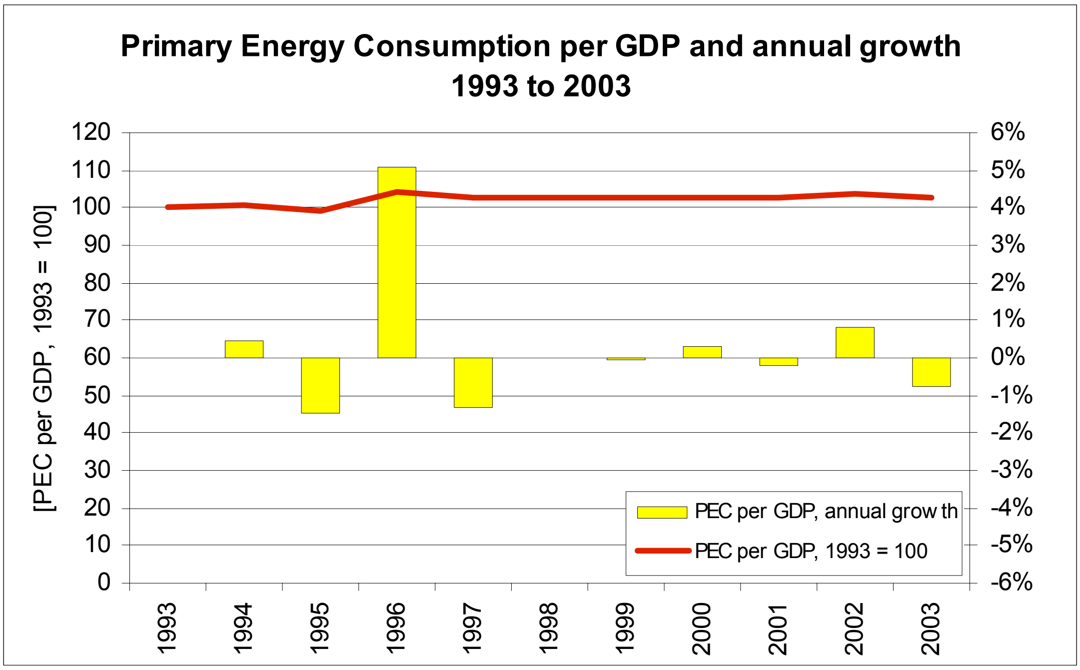
Primary Energy Consumption

The Primary Energy Consumption increased by about 43% from 1993 to 2003, which is an average annual growth of 3.6% (see picture below). The absolute Primary Energy Consumption raised from about 18,222 ktoe in 1993 to about 25,948 ktoe in 2003. [IDESCAT; Annuaris estadístics de Catalunya 1993-2006]



Picture 3: Index of Primary Energy Consumption 1993 to 2003, 1993 = 100, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006]

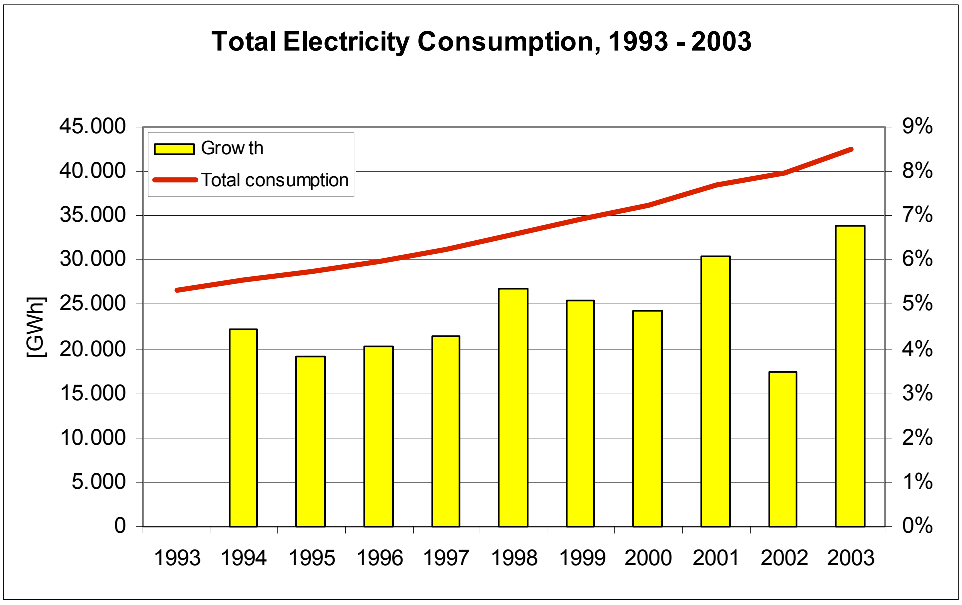
Looking at the PEC per Gross Domestic Product (GDP), the figure shows a slight increase of about 3% from 1993 to 2003, with an average annual increase of approx. 0.3%. In total there was a PEC of about 230 tons of oil equivalent per million € of GDP in 1993, which increased to about 235 toe/million € GDP in 2003 [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].



Picture 4: Development of the Catalonian Primary Energy Consumption per GDP and annual growth rates, 1993 to 2003, 1993=100, Sources of data: [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

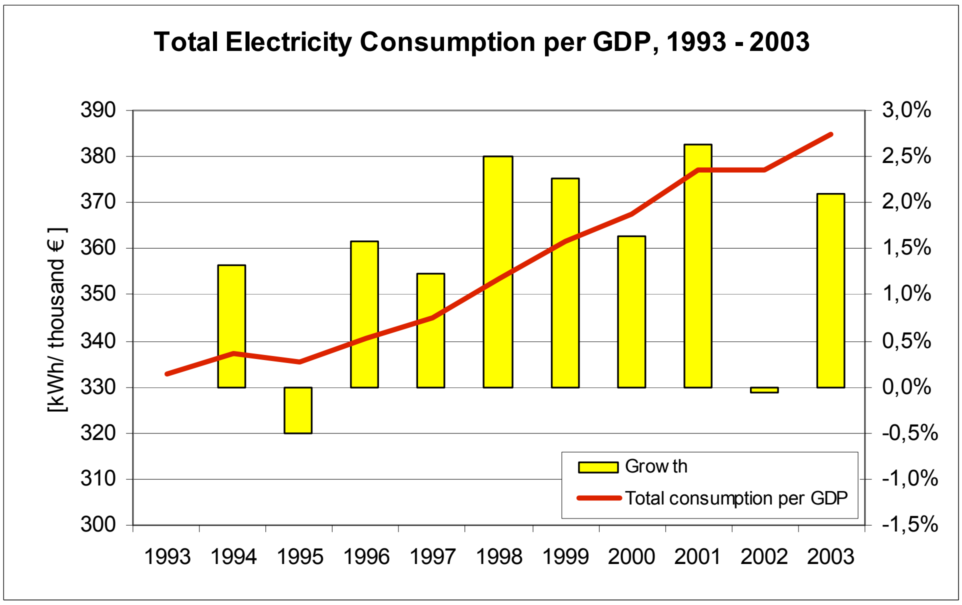
Electricity Consumption

Electricity consumption in Catalonia showed a steady growth from 1993 to 2003. With an average annual growth rate of about 5% per annum, electricity consumption increased by about 60% in total, from about 26,500 GWh in 1993 to about 42,500 GWh in 2003 (see picture below). [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].



Picture 5: Development of gross electricity generation and available electricity production in Catalonia, from 1993 to 2003, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

Since the growth in electricity consumption outperformed the GDP's, there was a massive increase in the electricity consumption per Gross Domestic Product figure (picture 6). From 1993 to 2003 electricity consumption per GDP raised from 333 kWh per thousand € to about 385 kWh / thousand €. This is an increase of almost 16% in total or 1.5 % on annual average.

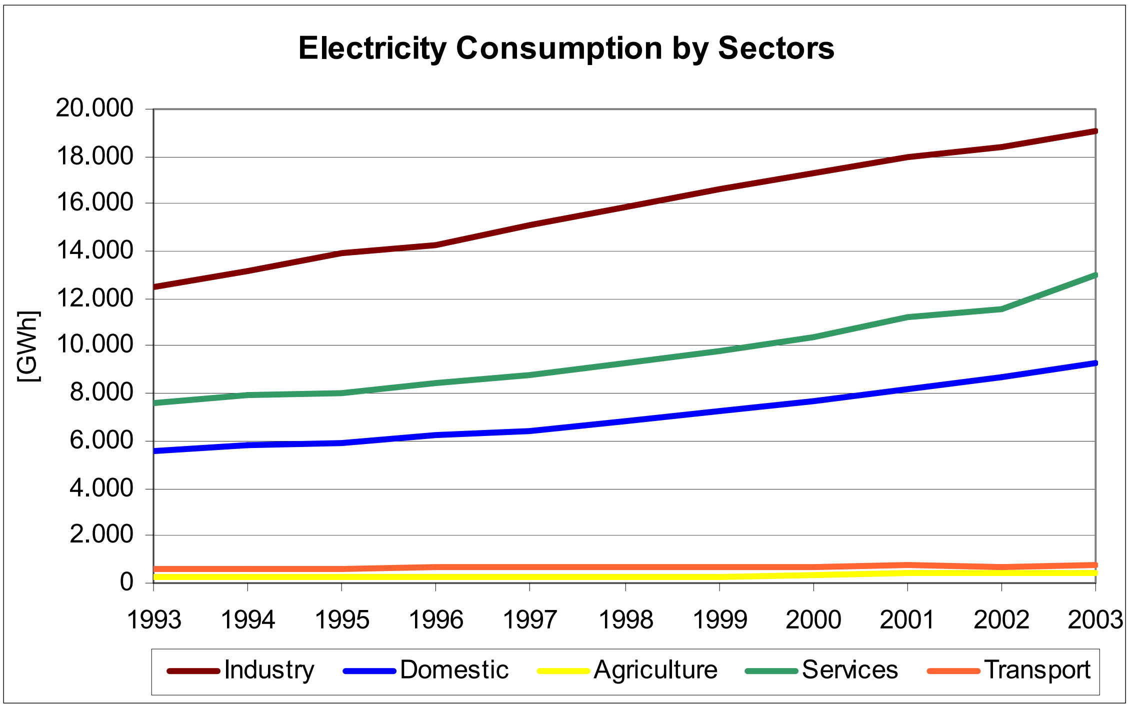


Picture 6: Development of the total electricity consumption and annual growth rates, 1993 to 2003, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

Electricity Consumption in the different Sectors

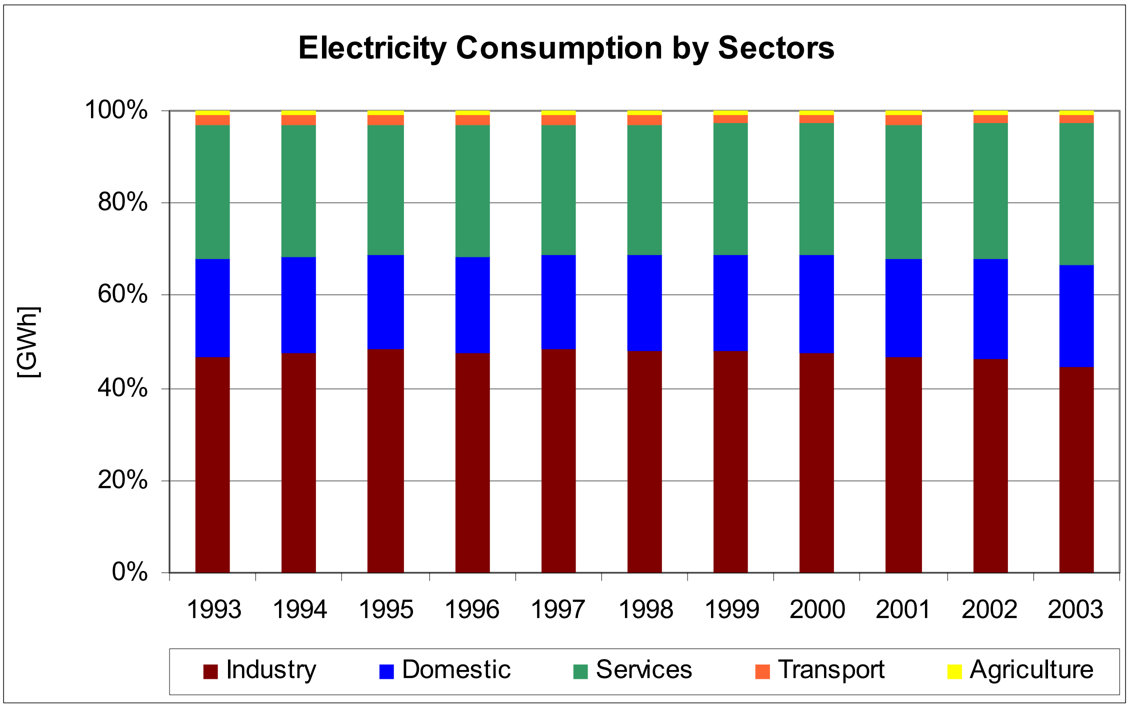
Major contributors to electricity consumption are the industrial (brown line), the commercial (green line) and the residential sectors (blue line). Agricultural sector (yellow line) and transport (orange line) sector's contribution is only marginal (see Picture 7)

In 2003 about 45% of the electricity consumed fell upon the industrial sector, followed by the services sector (about 30%) and the domestic sector with about 22%. Transport and primary together accounted for less than 3% of the total electricity consumption.



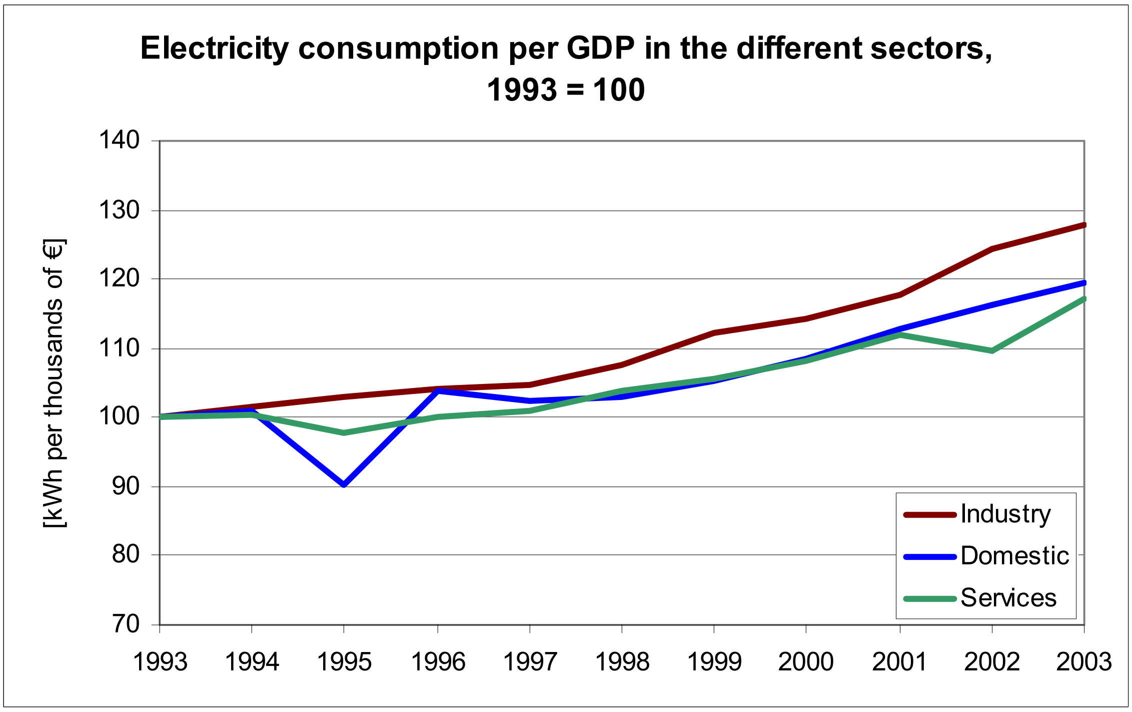
Picture 7: Development of Electricity Consumption by Sector, 1993 to 2003, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

From 1993 to 2003 there has not been a lot of change in the consumption structure (picture below). The industrial share increased somewhat from 1993 to 1997, but afterwards fell again to reach a level about 2.1% below the 1993 figure in 2003. The services sector appears to be the counterpart to this development, as the sector showed a slight increase from 1993 to 2003, reaching an about 2% higher share in 2003 than in 1993. Over all the years the domestic sector's share stayed within a margin of about 1.3%, reaching from 20.6 % to 21.9%. In 2003 the domestic sector consumed 21.8 % of all the consumed electricity.



Picture 8: Development of electricity consumption's structure by sector demand, 1993 to 2003, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

The sectored comparison of energy intensity (electricity consumption per GDP from 1993 to 2003, Picture 9) results in the industrial sector (red line) having the biggest increase in energy intensity (plus 28%), whereas the services sector (green line) shows an increase by 17%. While the increase in energy intensity accelerated after 2001 in the industrial sector, there was a temporarily decrease in the services sector from 2001 to 2002, followed by a steep increase from 2002 to 2003. The increase in energy intensity in the domestic sector (blue line, related to family income) was, with plus 19%, almost the same as in the services sector. All sectors show a noticeable trend towards a higher energy intensity from 1997 onwards. [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

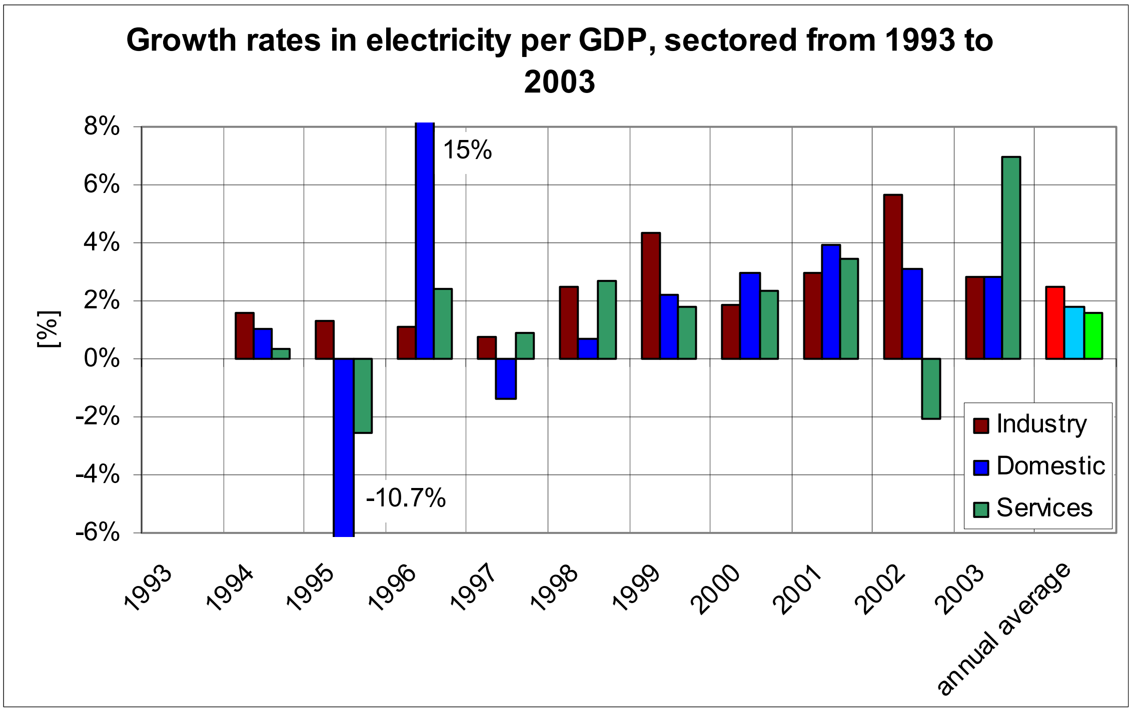


Picture 9: Electricity consumption per GDP in the different sectors, 1993 to 2003; 1993 = 100, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].

The annual rates of change (Table 1and Picture 10, below) reflect the increase in energy intensity in the years after 1997. Considering the long term annual average (1993 to 2003) for the three sectors, the industrial sector achieved an annual average increase of 2.5%, followed by the domestic sector (plus 1.8%) and the serevices sector with average annual increase in energy intensity of 1.6%. Only looking at the time from 1997 to 2003 the rates raise considerably to 3.4% for the industrial sector, 2,6% for the domestic and 2.5 % for the services sector.

	avergage annual increase in energy efficiency		
	1993 to 1997	1997 to 2003	1993 to 2003
Industry	1.2%	3.4%	2.5%
Domestic	0.6%	2.6%	1.8%
Services	0.3%	2.5%	1.6%

Table 1: Rates of change in energy intensity for the industrial, services and domestic sectors, 1993 to 2003, [IDESCAT; Annuaris estadístics de Catalunya 1993-2006].



Picture 10: Rates of change in energy intensity for the industrial, services and domestic sectors, 1993 to 2003

Projection of Energy Demand in Catalonia

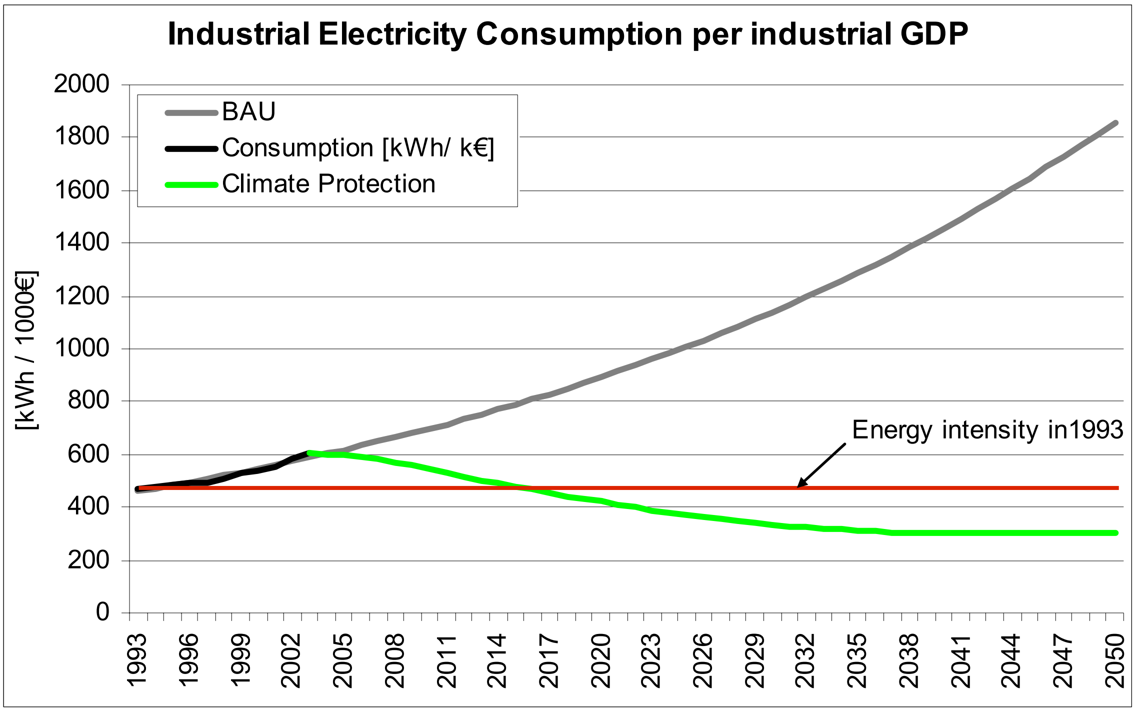
Industrial Sector

From 1993 to 2003 there was an increase in energy intensity of about 2.5% per year on average in the industrial sector. The projection of the past's development into the future, describing the trend if development in future goes on like it did in the past, forms the "business-as-usual" scenario here (BAU, grey line, Picture 11). According to this scenario electricity consumption per GDP will grow to more than three times of today's figure from 2003 to 2050.

The "Climate Protection" scenario (green line) assumes strong efforts in increasing electricity efficiency. It is assumed that efficiency improvements will speed up until 2010 and reach an annual gain of 2.5 % until then. This efficiency improvement speed is maintained until 2025. Afterwards the scenario assumption is that further increases in energy efficiency will be harder to achieve from year to year, as the value approaches to the scenario's threshold of 50% of the 2003 figure. Consequently there is a successive slow down in reduction rates, with no more reductions after 2040 and half of the 2003 energy intensity being reached in 2040.

Altogether the energy intensity reached in the "Climate Protection" scenario by 2050 is about 85% less than in the "business-as-usual" case. Considering the whole period, the annual average improvements in energy efficiency in the "Climate Protection" scenario are 1,4% per annum, which is in strong contrast to the further increase in energy intensity in the BAU case. As the "Climate Protection" scenario assumes a slow down in further energy efficiency gains, the average efficiency gains until 2030 are, with 2.2 % p.a., substantially higher than the average over the whole period.

In terms of absolute values the electricity intensity of the industrial sector in the "Climate Protection" scenario decreases from 600 kWh per thousand Euros (kWh/ k€) in 2003 to 300 kWh/k€ in 2050. A reduction to 1993's level will be achieved until 2017.

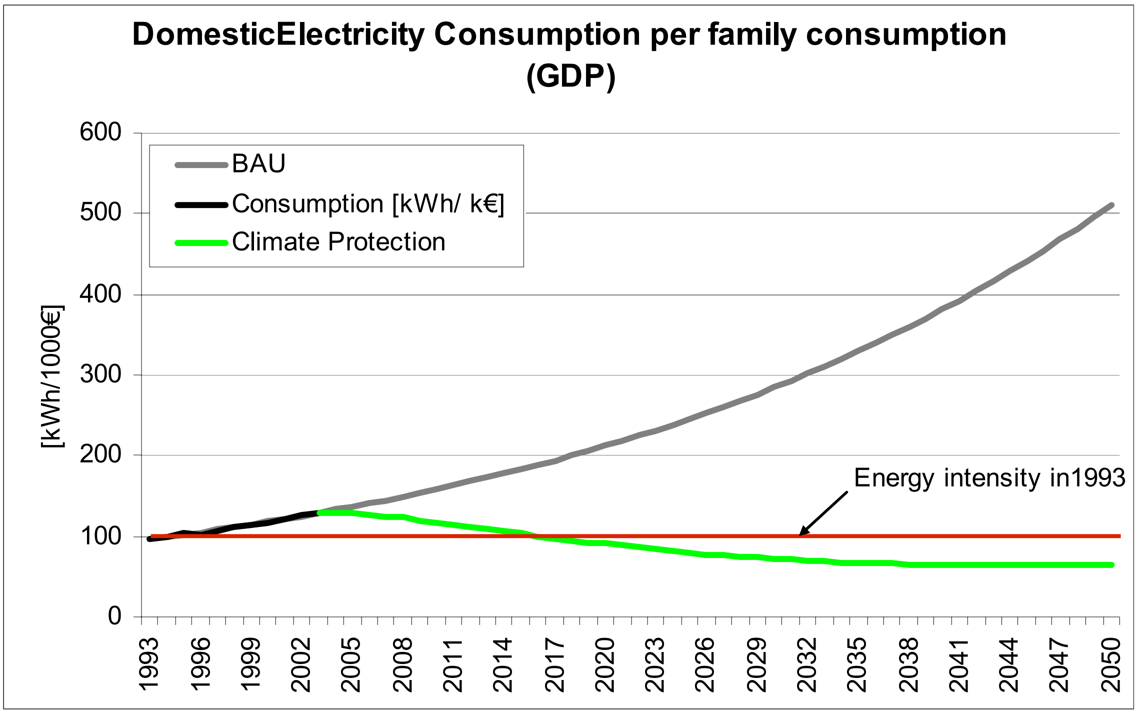


Picture 11: Development of energy intensity in the industrial sector, BAU case and "Climate Protection" scenario.

Domestic Sector

The assumption fort he „Climate Protection" scenario in the domestic sector (green line, Picture 12) are the same as in the industrial sector, with a Threshold at 50% of the 2003 energy intensity by 2050, a transition to more rapid efficiency gains until 2010 and a slow down in efficiency improvements from 2025 onwards.

The energy intensity by 2050 is 87% lower in the "Climate Protection" scenario as it is in the "BAU" case, which indicates a further growth in energy intensity. Most of the efficiency gains in the "Climate Protection" scenario occur until 2030, with a total reduction in energy intensity to about 45% of 2003's level. In terms of annual average for efficiency improvements in the "Climate Protection" scenario from 2003 to 2030 this is about 2.2% p.a. from 2003 to 2030 and about 1.4% considering the whole period (2003 to 2050). The absolute value of energy intensity in the "Climate Protection" scenario decreases from 130 kWh per million € of family consumption in 2003 to 65 kWh / mio. € in 2050. The 1993 level of energy intensity will again be reached by 2017.



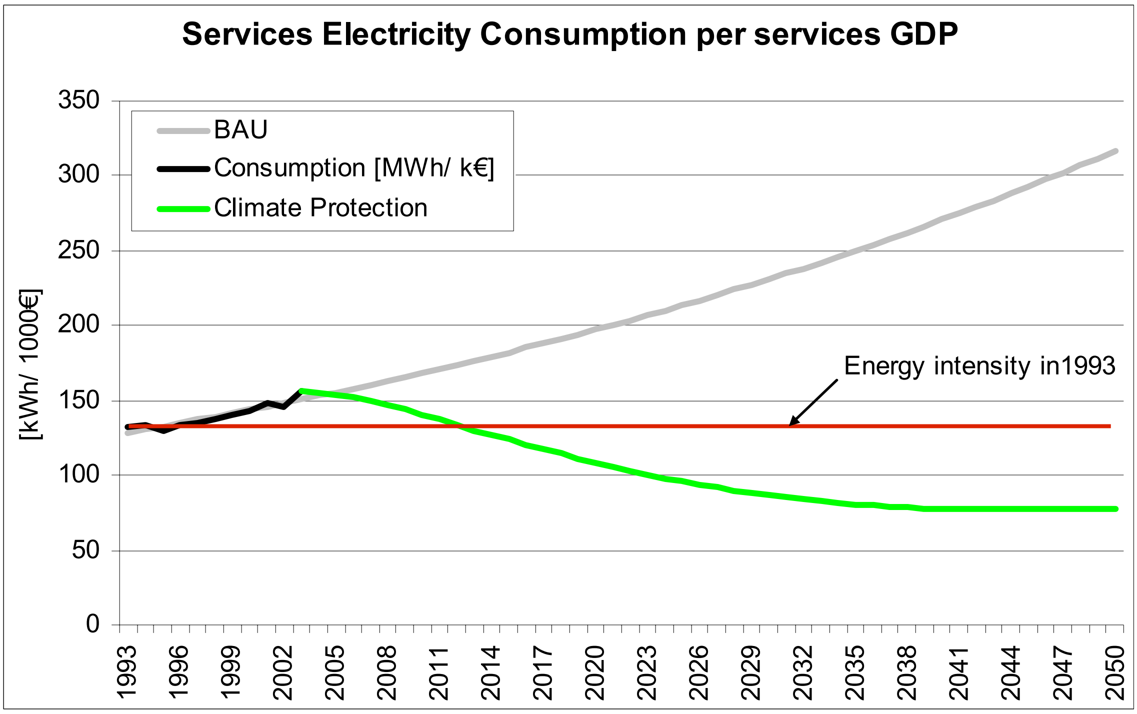
Picture 12: Development of energy intensity in the domestic sector, BAU case and "Climate Protection" scenario.

Services Sector

As in the other sectors, the trend development indicates a further massive growth in energy intensity per sectored GDP, leading to more than two times the energy intensity of 2003 by 2050.

In line with the assumption for the other sectors, the "Climate Protection" scenario assumes the annual average reduction from 2003 to 2050 as 1.4% and 2.2% from 2003 to 2030, due the assumed early efforts in energy efficiency improvements By 2050 energy intensity drops to half the energy intensity of 2003, which is then about 85% less energy intensity than in the BAU case.

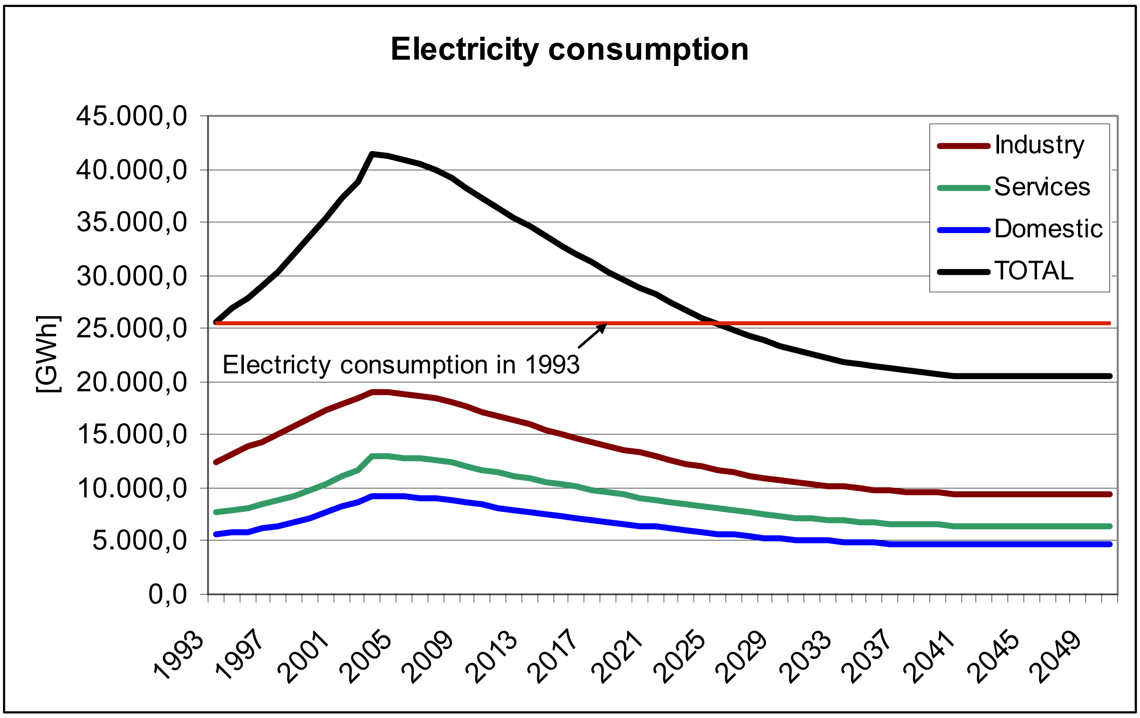
Considering the absolute energy intensity, this figure will drop from 156 kWh/k€ in 2003 to 78 kWh/k€ in 2050. The 1990' level of energy intensity will anew be reached by 2012.



Picture 13: Development of energy intensity in the domestic sector, BAU case (five year average and ten year average) and "Climate Protection" scenario.

Projection of the absolute electricity consumption

As there is no further increase in GDP assumed in the scenarios, the efficiency improvements directly reflect in the further development of absolute electricity consumption. Under this assumption the total electricity demand will decrease massively until 2030 - to about 56% of 2003's consumption - and then slowly approach to about the half of 2003 levels by 2040, with only minor reductions afterwards. By 2025 the electricity consumption will have come down to the level of electricity demand in 1993.



Picture 14: Development of the absolute electricity demand, no further growth in GDP assumed.

One reason for not assuming a further growth in GDP is that it is quite not possible to make a solid prediction of the GDP's development until 2050. World economy is changing at fast pace, with production sites or complete branches floating around the globe. This will massively change the economic structures, in the industrialized countries as well as in transition and developing countries. The bottleneck is, that we do not know how structures will change in detail and how it will impact energy consumption. Another reason is the fact, that economic growth with stable or increasing growth rates is an anomaly. Generally economies grow linear and not exponential, i.e. a growth by the same amount year per year. This growth characteristic can be shown by analysing the development of national economies from 1950 to the present [Afheldt; 2003]. After all, if we take climate change seriously and we are willing to act consistent, the global economy has to change to a less resource intense economy, e.g. by turning away from short-lived bulk goods, returning to repairable goods, replacing energy intense materials by other materials etc..

Lastly we are convinced that reductions in the magnitude as described here are possible, even with a further growing GDP. The study "EUROPEAN ENERGY AND TRANSPORT SCENARIOS ON KEY DRIVERS" comes to a similar conclusion with stating that energy demand in the EU could be reduced to levels comparable to 1990 *"…Total EU-25 energy consumption in the "Energy efficiency" case comes virtually back to the 2000 level in 2020 (there is just a marginal increase of 0.5 % over 20 years from 1653 Mtoe in 2000 to 1662 Mtoe in 2020). In 2030, total energy consumption would be even as low as it had been in 1990 (there would be even a slight decrease of 0.8% over 40 years to reach 1544 Mtoe in 2030)…"* [EU; 2004].

Conclusion

Although Catalonia showed a strong economic growth within the past ten years, Catalonia did not perform well with regard to energy intensity. It is quite clear that energy intensity in the Catalonian economy must be reduced in order to shift to a sustainable energy supply and to make it's own contribution to climate protection. The scenarios within this work highlight a development towards halving electricity intensity in the three most important sectors of electricity consumption until 2050. This, of course, means making great efforts to improve the efficiency of electricity use, but we are convinced that this is feasible from a technological point of view. Further technological development towards more efficient appliances will assist such a development and restructuring our economies and redefining the relationship between energy consumption and wealth may be necessary but, in the end, climate change and it's serious consequences will force us to walk this way. After all one fact is quite clear: we have to start now in order to keep transition smooth and to avoid the most serious consequences of climate change.

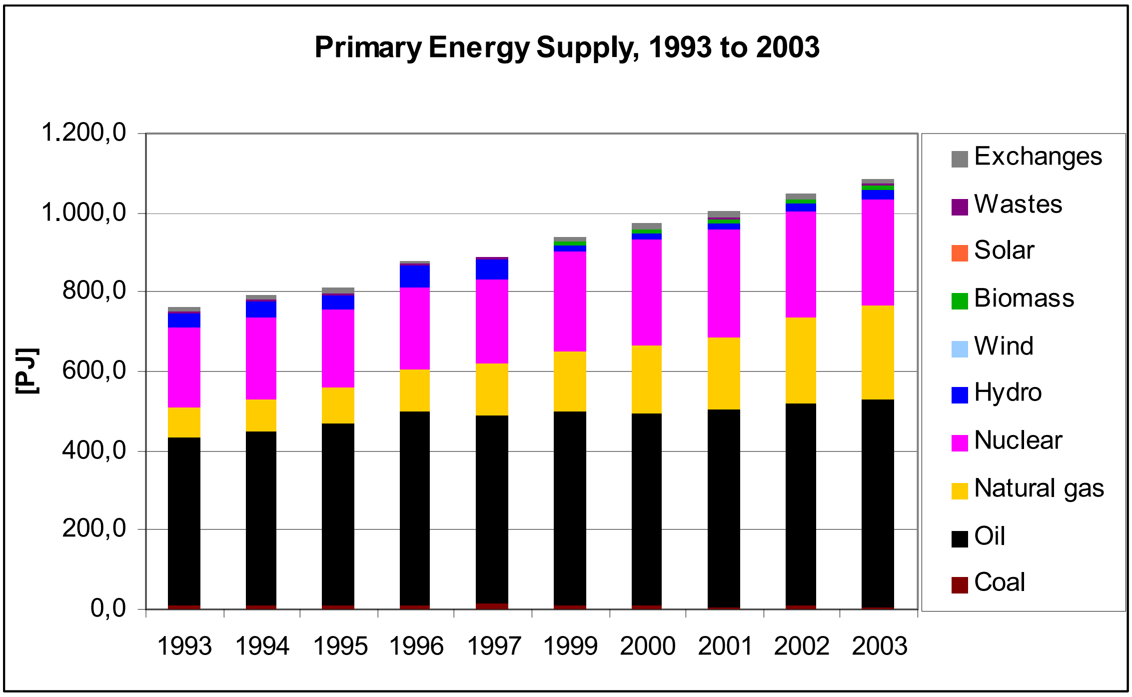
Taking the development as proposed here will bring down Catalonia's electricity consumption to the 1993 level until 2025 and to the half of 2003's electricity consumption by 2050. Even with respect to the facts, that further reductions will be harder to achieve the further we step into future and that a certain level of energy intensity will remain, the developments presented here show two remarkable facts: although getting energy intensity down to the half sounds very hard, half of the way solely consist of revoking the increase in energy intensity from 1993 to 2003. The remaining effort in efficiency improvements (compared to the efficiency Catalonia already had in 1993) is not of an extend that should make us doubt that this goal can be achieved.

Energy Supply Module

Development of Energy Supply in Catalonia's and current Energy Supply

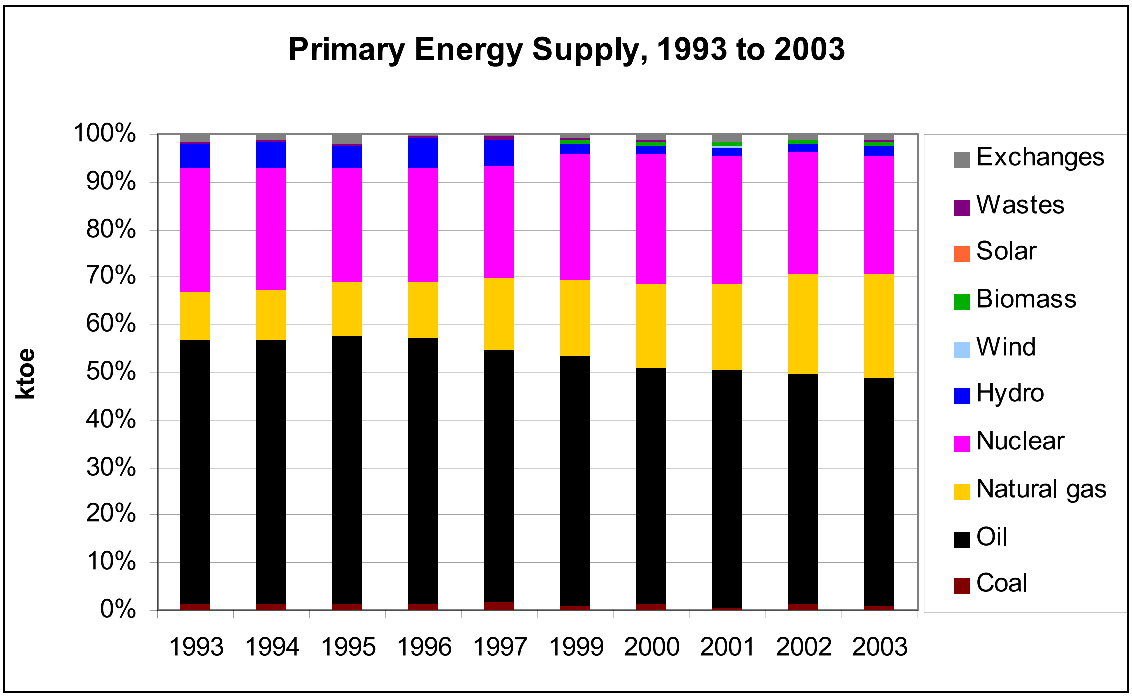
Primary Energy Supply

Primary Energy Supply (PES) increased from about 763 PJ in 1993 to about 1,186 PJ in 2003, a total increase by 42%. Especially Natural Gas gained importance, showing the biggest increase of all energy sources, followed by Oil and Nuclear Energy.



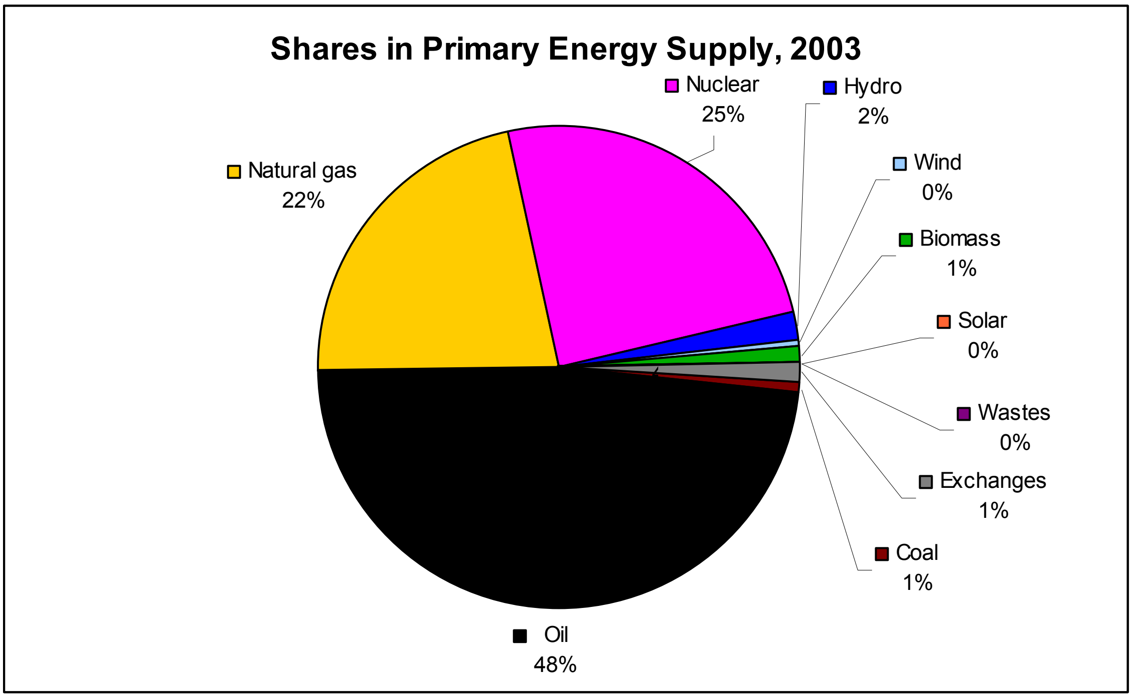
Picture 15: Development of Primary Energy Supply, 1993 to 2003 [IDESCAT; Anuaris del període 1993-2003]

The share in primary energy supply of Natural Gas raised from about 10% in 1993 to about 22% in 2003. Oil showed a slight loss in share with 55% in 1993 and 48% in 2003. The contribution of nuclear energy remained almost unchanged (26% in 1993 and 25% in 2003). Hydropower lost importance, with a decrease in share of about 3% from 1993 to 2003 (share of about 5% in 1993 and about 2% in 2003).



Picture 16: Sources of Primary Energy 1993 to 2003 [IDESCAT; Anuaris del període 1993-2003].

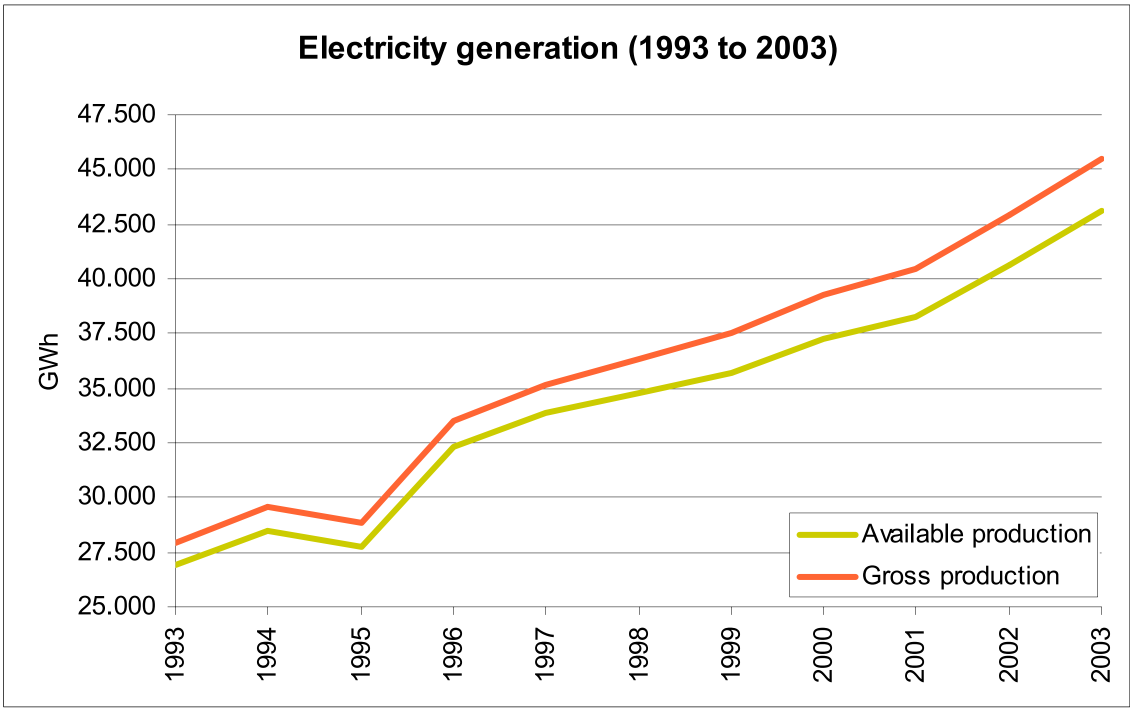
In 1993 fossil fuels contributed about 71% to primary energy supply (Oil 48%, Natural Gas 22% and Coal 1%). Another quarter came from nuclear energy. Energy from renewables and waste had a share of about 3%.



Picture 17: Primary Energy Supply structure in 2003 [ICAEN, PEC 2006-2015]

Final Energy Supply: Electricity generation

With an exception in 1995, electricity generation in Catalonia showed a steady growth from 1993 to 2003. With an average annual growth rate of about 5% per annum, gross electricity generation increased from 28,000 GWh in 1993 to about 45,500 GWh in 2003 (see Picture 18).



Picture 18: Development of gross electricity generation and available electricity production in Catalonia, from 1993 to 2003 [IDESCAT, Anuaris del període 1993-2003].

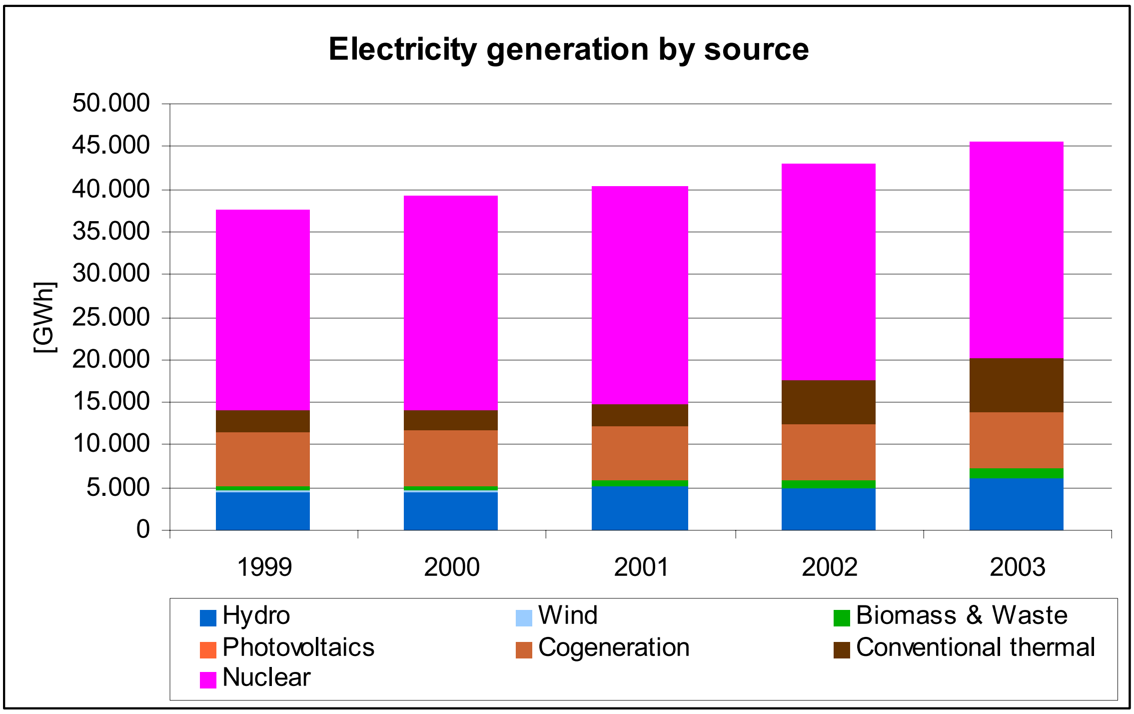
Most of the additional electricity generation was covered by an extended use of fossil fuels and nuclear power (see Table 2 and Picture 19). While the electricity generation of conventional thermal power plants increased by about 4,900 GWh from 1993 to 2003, this figure is about 4,100 GWh for nuclear power, approx. 1,900 GWh for hydro energy and 162 GWh for wind energy.

Increase in electricity generation [GWh]				
	average annual increase		increase in 2003	increase from 1993 to 2003
	1994 to 1999	1999 to 2003		
Hydro	156,8	225,2	1206,0	1910,0
Wind	9,3	23,1	-9,0	162,0
Conventional thermal1)	282	689,8	797,0	4859,0
Nuclear	342	487,2	76,0	4146,0
Gross production	1679,8	1818,8	2493,0	17493,0
Available production	1579,2	1655	2399,0	16171,0

1) including cogeneration

Table 2: Average annual increase in electricity generation, increase in 2003 and total increase from 1993 to 2003 [from IDESCAT, Anuaris del período 1993-2003, own elaboration].

Picture 19 shows impressively the predominance of nuclear power generation in the electricity sector, contributing about 57% to the total electricity generation in 2003. Cogeneration, conventional thermal and hydropower make up for about the same shares in electricity generation (in the range of 13% to 14% each). Biomass contribution is far lower (about 3%) and electricity generation by wind energy is almost invisible on this scale (below 1%).



Picture 19: Electricity generation by sources, 1992 to 2003 [IDESCAT; Anuaris del període 1993-2003].

Renewables in Electricity Supply

Electricity Production by Renewables

Looking at the renewable electricity generation (Table 3) it is obvious that hydropower (6,039 GWh in 2003, about 82% of the total renewable electricity) has by far the lead. Second-best contribution comes from Biomass & Waste (about 1,190 GWh in 2003, approx 16% of the total renewable electricity), followed – with a big gap - by wind energy (about 163GWh, 2.2%) and photovoltaics (about 2 GWh, 0.03%).

Renewable Electricity generation [Gwh]	**1999**	**2000**	**2001**	**2002**	**2003**
Wind	88	138	163	172	163
Biomass & Waste	427	513	683	855	1.186
Photovoltaics	1	1	1	1	2
Hydro	4.534	4.496	5.068	4.833	6.039
Shares of Renewable Generation					
Wind	1,7%	2,7%	2,8%	2,9%	2,2%
Biomass & Waste	8,5%	10,0%	11,5%	14,6%	16,0%
Photovoltaics	0,02%	0,02%	0,02%	0,02%	0,03%
Hydro	89,8%	87,3%	85,7%	82,5%	81,7%

Table 3: Electricity generation from renewables 1999 to 2003 and share of sources at total renewable generation [IDESCAT; Anuaris dels períodes 1993-2003].

Potentials of renewable energy sources in Catalonia

Solar photovoltaics (PV)

In different publications the potential of photovoltaics in Catalonia is described within the range of 450 MW (Catalonian Energy Plan, [CEP; 2005]) up to 127,800 MW (Renewables 2050, [GP; 2005]). About 78,600 MW of the higher potential estimation is building integrated photovoltaics, the rest are central PV plants. The Solar PV potential written in the Catalonian Energy Plan (450 MW) does not differentiate between different types of installation.

Publication	**Type**	**Potential (GW)**	**Production (TWh/a)**	**Full Load hours**
Renewables 2050	building integrated1)	78.6	90.49	1,151.26
	Central plants2)	19.1	37.27	1,951.16
	total3)	97.7	127.76	1,307.68
Catalonian Energy Plan	total3)	0,45	0.518	1,151.26

1) this is 5.8% of the total potential in Spain

2) this is 2.7% of the total potential in Spain

3) calculated with productivity from Renewables 2050 [GP; 2005]

Table 4: Overview of photovoltaic potential description for Catalonia in different publications

Considering the number of residential houses alone, with the assumption of installing 1kWpeak on single family or 2 kWpeak on multifamily buildings on the roof of these buildings, shows that the potential estimation given by the Catalonian Energy Plan represents a massive underestimation of Catalonian PV potentials. There are more than 2.3 million residential houses in Catalonia. The installable capacity amounts to more than 4120 MWpeak, which is about 8 times the amount given by the Energy Plan. This does not include other building-types, such as public, industrial or commercial buildings.

The IER scenario developed in the Energy Plan plans to reach 100 MWp of solar PV in 2015. [CEP; 2005].

Building type	**Number of buildings**	**Installation per building**	**potential**	**production1)**
Single Family	504,056	1kWpeak	0.504 GW	0.5802 GWh
Multifamily	1,811,718	2 kWpeak	3.623 GW	4.171 GWh
TOTAL	2,315,774	-	4.127 GW	4.751 GWh

1) calculated with productivity from [Renewables 2050]

Table 5: Estimated PV potential on residential buildings. Source of building-data [Institut Cerdà, La contribució de l'habitatge de Catalunya a la reducció de les emissions de gasos d'efecte hivernacle, Departament de Medi Ambient i Habitatge, 2006]

Solar Thermal Plants

According to the "Renewables 2050" publication the potential for Solar Thermal Power Plants in Catalonia is about 153GW (see Table 6), with a possible electricity production of about 553 TWh per year [GP; 2005]. The Catalonian Energy Plan foresees erecting only one Solar Thermal Power plant with a capacity of 50 MW_{el} [CEP; 2006].

Publication	**Technology**	**Potential (GW)**	**Production (TWh/a)**	**Full Load hours**
Renewables 2050	Solar Thermal Power	153	553	3613

Table 6: Potential of Solar Thermal Power Plants in Catalonia according to the "Renewables 2050" study [GP; 2005].

In this study we estimate that it is possible to build 500 to 600 MW_{el} generating capacity in 10 to 12 Solar Thermal Power Plants in Catalonia at least (50 MW generating capacity per plant).

Wind Energy

The publication “Renewables 2050” outlines a wind energy potential of about 53 GW onshore and about 20 GW offshore, totalling to more than 70 GW of installable capacity (Table 7). Besides the huge potential, the publication states an high load factor for onshore wind energy, with an average productivity of almost 2,500 kWh a year per kW of installed capacity. The offshore figure is remarkably lower, with about 2,000 kWh of electricity generation per kW installed capacity [Renewables 2050].

Renewables 2050	**Location**	**Potential (GW)**	**Production (TWh/a)**	**Full Load hours**
Onshore		53	132.4	2,497
Offshore, up to 100m depth	Tarragona	14.72	29.8	2,027
	Barcelona	3.45	7.0	2,027
	Girona	2.04	4.1	2,027
	Total	20.21	41.0	2,027

Table 7: Catalonian onshore and offshore wind energy potentials according to the „Renewables 2050“ [GP; 2005].

Another study on offshore wind energy – “SeaWind Europe”, published by Greenpeace – describes an offshore wind energy potential of about 56 Gw to about 276 GW, considering different water depths and different distances from the coastline (Table 8).

SeaWind Europe	**until 2010**	**until 2015**	**until 2020**
distance to land [km]	5-30	5-40	5-30
deep sea bed [m]	30	50	100
technically available area [lm2]	7,042	12,636	33,340
Potential [GW]	56.3	101.1	266.7

Table 8: Catalonian offshore wind energy potential of the “SeaWind Europe” study [GP; 2004].

In contrast to the publications mentioned above, the Catalonian Energy Plan provides a substantially lower wind energy potential estimation for Catalonia. In total the Energy Plan describes a potential of about 5 GW [CEP; 2005].

Considering the classification of areas by the related mean annual wind speed, provided by the Catalonian Energy Plan (Table 9), it is possible to calculate the potential of onshore wind energy, by considering assumptions regarding specific installation rates (e.g. plants per km2) or restrictions in area use.

Table 9 gives an overview of the underlying assumptions for the potential estimation, which generally considers using plants with 2.5 MW capacity and a windpark size of 18MW on average.

Wind speed at 80 m height	**related areas**	**average plants per km²**	**fraction of total area used**
[m/s]	**[km²]**	**[plants/km2]**	**[%]**
0 – 5,5	20.675,1	0	-
5,5 – 6	3.909,9	0,25	3,5%
6 – 6,5	3.014,6	0,25	3,5%
6,5 – 7	2.191,8	0,25	3,5%
7 – 7,5	1.082,6	0,25	6,9%
7,5 – 8	552,0	0,5	6,9%
8 – 8,5	284,7	0,5	10,4%
8,5 – 9	159,6	0,75	10,4%
9 – 9,5	95,5	0,75	10,4%
9,5 – 10	61,1	0,75	10,4%
10 – 10,5	38,3	1	13,9%
10,5 – 11	21,7	1	13,9%
11 – 11,5	8,3	1	13,9%
11,5 – 12	3,1	1	13,9%

Table 9: Assumptions for onshore wind energy potential estimation [CEP; 2005], [own calculation].

An installation of 1 plant per square kilometre in average is considered in areas with a mean annual wind speed above 10 m/s. For areas with lower wind speed this specific installation is assumed to be less (see Table 9). As the installation of wind power plants will be in windparks and not as single plants spread over the whole country, the assumed average cluster size (18 MW) leads to a significant reduction of the total area which is covered by windparks. For an average of 1 plant per km2 clustering reduces the fraction of area that is used for windparks to about 14%. This decreases to 3.5% with an assumed specific installation of 0.25 plants per km2.

As areas with a mean annual wind speed below 5.5 m/s were not considered, the total onshore wind energy potential results to about 8,200 MW (see Table 10)

Windspeed at 80 m height	**Number of plants**	**Installable capacity**	**real area used for windparks**	**Total area per wind speed class**
[m/s]	**[pieces]**	**[MW]**	**[km2]**	**[km2]**
0 – 5,5	0	0	-	20.675,1
5,5 – 6	977,5	2443,7	135,8	3.909,9
6 – 6,5	753,7	1884,1	104,7	3.014,6
6,5 – 7	548,0	1369,9	76,1	2.191,8
7 – 7,5	270,7	676,6	37,6	1.082,6
7,5 – 8	276,0	690,0	38,3	552,0
8 – 8,5	142,4	355,9	19,8	284,7
8,5 – 9	119,7	299,3	16,6	159,6
9 – 9,5	71,6	179,1	9,9	95,5
9,5 – 10	45,8	114,6	6,4	61,1
10 – 10,5	38,3	95,8	5,3	38,3
10,5 – 11	21,7	54,3	3,0	21,7
11 – 11,5	8,3	20,8	1,2	8,3
11,5 – 12	3,1	7,8	0,4	3,1
TOTAL	3,267	8,192	455	32.098

Table 10: Overview of onshore wind energy potential by wind speed class and area.

The total area that gets utilised for onshore wind energy installations is about 455 km2, which is about 1.4% of the total wind energy potential area as described by the Energy Plan.

The potential given in Table 10 (8.2 GW) is substantially lower if compared to the potential given by the "Renewables 2050" study (53 GW). For the development of the Energy Supply Scenarios in this study the lower potential of 8.2 GW, based on the data provided by the Catalonian Energy Plan, gets used.

The potential for offshore wind energy used here assumes that 1,000 MW offshore wind energy capacity can be installed along the southern part of the Catalonian coast line at least. According to the windmap provided by the Catalonian Energy Plan there are excellent resources for offshore wind energy in the southern part of Catalonia

Hydropower

The "Renewables 2050" study states a hydropower potential of about 2,300 MW for Catalonia. Considering that this figure is identical to the already existing hydropower plants in Catalonia (about 2,300 MW), there is no potential remaining for a further extension of hydropower.

Nevertheless, the Catalonian Energy Plan describes the possibility of adding about 154 MW of additional hydropower in Catalonia, of which about 30 MW are large scale hydropower plants and about 123 MW small hydropower plants [GP; 2005], [CEP; 2005].

Base Scenario	**2015**	
Additional Potential	51,1	GW
large hydropower	30,3	GW
small hydropower	19,8	GW
Additional production	179,9	GWh
large hydropower	102,1	GWh
small hydropower	77,8	GWh
IER Scenario	**2015**	
Additional Potential	153,6	GW
large hydropower	30,3	GW
small hydropower	123,3	GW
Additional production	583,5	GWh
large hydropower	102,1	GWh
small hydropower	481,4	GWh

Table 11: Additional hydropower potential in Catalonia up to 2015, according to the Catalonian Energy Plan [CEP; 2005]

Biomass & Waste

According to the "Renewables 2050" publication by Greenpeace the biomass potential in Catalonia, including combined heat & power, is about 1.5 GW.[Renewables 2050]

The Catalonian Energy Plan describes an additional biomass potential of up to about 14,400 GWh by 2015, with about 3,370 GWh already being utilized in 2003 (see Table 12, IER Scenario, total Potential 2015: 17,760 GWh). About 9,500 GWh of this additional potential applies to biofuels. Consequently the potential for electricity generation, whether this might be in cogeneration plant or power plants, quoted in the Energy Plan results to about 4,870 GWh.

Base Scenario	**2003**	**2010**	**2015**
Forest & agricultural	1092	1480	1589
Biogas	264	1365	1397
Renewble waste	1718	1707	1707
Biofuels	294	2483	2481
Biodiesel	63	2254	2254
Bioethanol	231	229	156
TOTAL	**3368**	**7036**	**7173**
IER Scenario	**2003**	**2010**	**2015**
Forest & agricultural	1092	2104	3240
Biogas	264	1891	2391
Renewble waste	1718	1939	2312
Biofuels	294	4393	9817
thereof Biodiesel	63	4151	9134
thereof Bioethanol	231	242	683
TOTAL	**3368**	**10326**	**17760**

Table 12: Use of biomass and biomass potential up to 2015 according to the Catalonian Energy Plan [CEP; 2005]

The electricity that can be generated from the above given potential, relies on the applied electricity generating technologies and the distribution between cogeneration and pure electricity generation.

Assuming that forest & agricultural biomass, biogas and renewable waste are available for electricity production (including cogeneration) an installable capacity can be assessed. Provided that cogeneration plants have an electrical efficiency of 30% on average [Dienhart, J. Nitsch; 2002] and an efficiency of 40% for pure electricity production, which is about the efficiency of a typical conventional power plant, with a cogeneration share of 50% and an annual load factor of 0.6 (about 5,260 equivalent full load hours a year) the additional installable capacity results to about 324 MW, of which about 139 MW are in cogeneration plants. The biofuels fraction of the biomass potential was set aside for other use (e.g. transport) in this study.

Plant Type	Resource	Electrical efficiency	Full load hours per year	installable capacity
Cogeneration	forest & agricultural biomass, biogas and renewable waste	30,00%	5256	138,97
Power plants	forest & agricultural biomass, biogas and renewable waste	40,00%	5256	185,29
			Subtotal	**324,26**
Cogeneration	biogas	30,00%	5256	271,76
Power plants	biogas	40,00%	5256	362,35
			Subtotal	**634,12**
Cogeneration	all fractions	30,00%	5256	410,73
Power plants	all fractions	40,00%	5256	547,65
			TOTAL	**958,38**

Table 13: Installable capacities for electricity production from biomass, considering different biomass fraction of the potential as described in the Catalonian Energy Plan. [CEP; 2005], [SoCAT; 2007, own calculation]

This is considerably lower than the potential described in the "Renewables 2050" study (1.5 GW including cogeneration). It has to be noted here that the "Renewables 2050" study considered all biomass fractions – including bio fuels - for electricity production. The potential used in this study (324 MW) does not consider bio fuels to be used for electricity production. If bio fuels – with the potential as described in the Catalonian Energy Plan - are additionally considered for electricity generation the installable generating capacity would almost triple to about 960 MW.

Geothermal electricity production

While the "Renewables 2050" describes a geothermal potential for electricity generation of 176 MW, there is no geothermal power production designated within the Catalonian Energy Plan.

In this study the Geothermal potential provided by the "Renewables 2050" study is considered for scenario development.

Overview of used potentials

The potentials described above provide a spectrum of potentials for the different technologies. In general the described potentials of renewables energy sources vary in different publications. This is not a sign for one estimation being generally better than others, but rather depends on the underlying assumptions, e.g. considered restrictions, assumed technological development, etc.. In this study we tried not to carry potential estimations to the extreme. This approach gets for example reflected in the fact that no technological future development has been considered or that we chose a moderate installation density for wind energy. Table 14 gives an overview of the potentials being used for scenario development.

Technology	**Potential (GW)**	**Base**
Photovoltaic	4.1	own assessment
Solar Thermal Power	0,6	own assessment
Wind onshore	8.2	own assessment, wind data from Energy plan
Wind offshore	1	own assessment
Additional Hydropower	0.15	Energy Plan
Biomass	0.32	assessed from Energy Plan data
Geothermal	0.18	Renewables 2050

Table 14: Overview of the potential considered for scenario development, [CEP; 2005], [GP; 2005] [SoCat; 2007, own estimation].

Energy Supply Scenarios

Some still neglect that renewable energies will ever be able to supply our need for energy due to the limited potentials and the huge amount of energy we need. They are surely right, if we do not start to use energy more efficient than we do today, but the energy efficient technologies, necessary to cap energy demand as described in the Energy Demand Module, are already on-hand. Others will surely be developed and further efficiency potentials are closely related to the way global economy acts and how we define prosperity. The supply scenarios developed in the following will demonstrate how the demand for electricity in Catalonia can be covered by regional renewable energy sources.

The dominating stimulus for extending the generation capacities of renewable technologies within the SolarCatalonia scenarios is an assumed renewable energies introduction framework to attract investments into renewable energies. This incorporates that specific targets for an extension of renewable technologies are provided by policy and that these targets are supported by sufficient financial incentive (e.g. such as feed-in tariffs), appropriate administrative regulations, with simple and transparent approval procedures and favouring renewables instead of conventional energy technologies, the removal of hindrances and establishing fair market conditions (e.g. by internalising the external costs of conventional energy production).

The scenarios are target oriented but respect the potentials as described above (see Potentials of renewable energy sources in Catalonia) as limitations to the further renewable energies extension. This study provides two scenarios for the introduction of renewable technologies into the Catalonian electricity system, one targeting a 100% electricity supply from renewables by 2050 ("Climate Protection Scenario") and the other targeting an 80% renewable electricity supply by 2030 ("Fast Exit Scenario").

The development path of the single technologies towards 2050 is described by the so called "logistic-growth", which represents a "growth with constraints", in contrast to a pure exponential growth, which describes a process of unlimited growth[12]. The upper limitation for growth is provided by the potential of each single technology in Catalonia (see also Potentials of renewable energy sources in Catalonia).

In order not to neglect the financial aspect of an extension of renewable energies, an additional restriction was introduced for scenario development: the annual investment costs for renewable energy technologies should not exceed an amount of 100 € per year and inhabitant

[12] The logistic growth concept is often used to describe growth processes in nature but also for economic growth processes.

Extension strategy

The basic consideration for extending the generating capacities for each technology was to favour adjustable energy technologies. Fluctuating energy producers, i.e. wind energy and photovoltaics, are considered second. The consequence of this approach is that the speed of exploitation for such renewable sources that offer adjustable electricity generation is higher than the exploitation speed of fluctuating sources, although all technologies get extended simultaneously. This approach was chosen as a contribution to grid regulation capabilities and stability & reliability of electricity supply.

Growth characteristics in the scenarios

The general approach of mapping the development of single renewable technologies to the timeline is using so called "logistic growth functions", showing the typical s-curved shape for growth with saturation effects in the later stage of development. This reflects the underlying assumption is that growth cannot be unlimited if any of the resources growth depends on is limited.

Specific investment costs for renewable technologies and cost degression

As the scenarios incorporate the financial aspect, it was indispensable to make assumptions regarding the future development of technology specific investment costs. There are different assumptions for the different technologies. While wind energy, geothermal power plants, biomass plants and solar thermal power plants are expected to show a decrease of specific investment costs to the half of today's costs by 2050, the specific costs of photovoltaics are expected to fall to one third of today's costs. No cost degression is assumed for hydropower (see Table 15).

Technology	**Investment costs today [$€_{2006}$/kW_{el}]**	**Investment costs 2050 [$€_{2006}$/kW_{el}]**
Biomass and Waste	4,440	2,200
Wind onshore	1,200	600
Wind offshore	1,800	900
Photovoltaics	5,000	1,667
Solarthermal Power	4,000	2000
Geothermal Power	8,000	4,000
Hydropower	6,350	6,350

Table 15: Initial specific investment costs and specific investment costs by 2050.

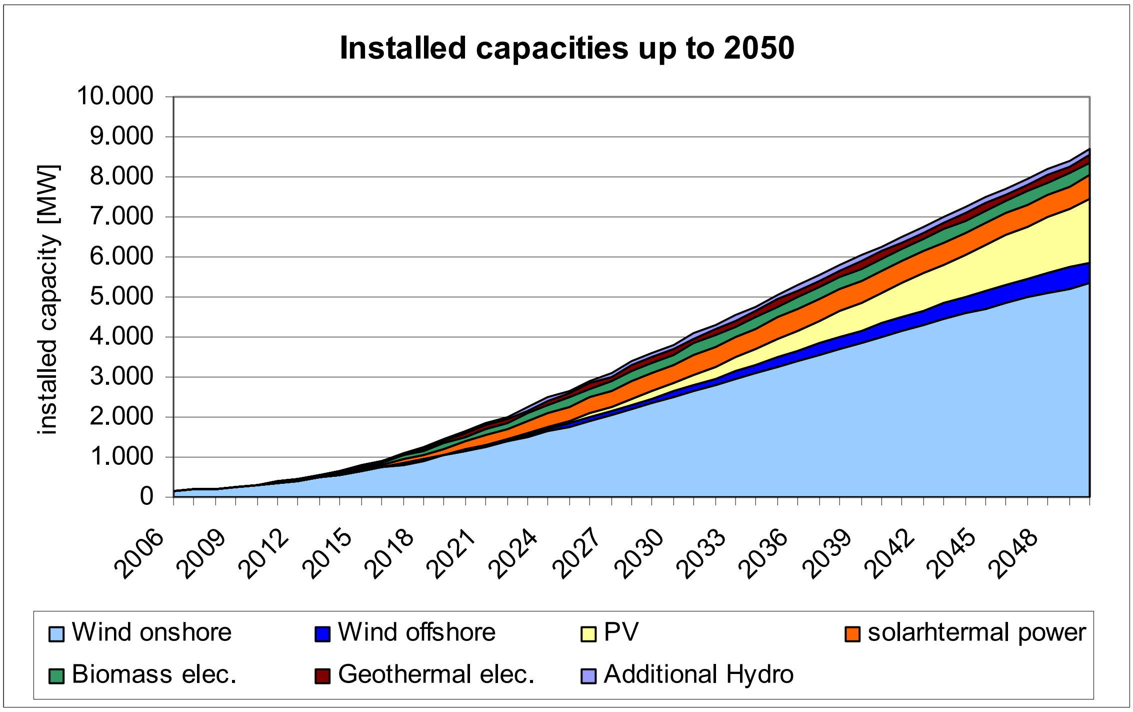
Introductory Scenarios

In the following to introductory scenarios for renewable technologies in Catalonia will be presented. Both scenarios utilise the same logistic growth approach, but differ in development speed. The "Climate Protection Scenario" (CPS) aims at reaching a 100% electricity supply from renewable sources by 2050. The second scenario – "Fast Exit Scenario" (FES) – shows a development path to supply 80% of the Catalonian electricity demand by 2030.

As the scenarios cover the development up to 2050, it is considered that plants reach the end of their lifecycle within this period and must be displaced by new plants.

The "Climate Protection Scenario"

The new added generating capacities of renewables (Picture 20) increases to 3.9 GW by 2030 and further to 8.7 GW by 2050. Wind energy accounts for most of the new capacity (68% 2030 and 2050; onshore & offshore wind), followed by photovoltaics (6% in 2030 and 18% in 2050) and solar thermal power plants (13% in 2030 and 7% in 2050). Biomass, geothermal and additional hydropower's contribution to the generating capacity is substantially lower.



Picture 20: Climate Protection Scenario, Development of installed capacities until 2050 [SolCat; 2007]

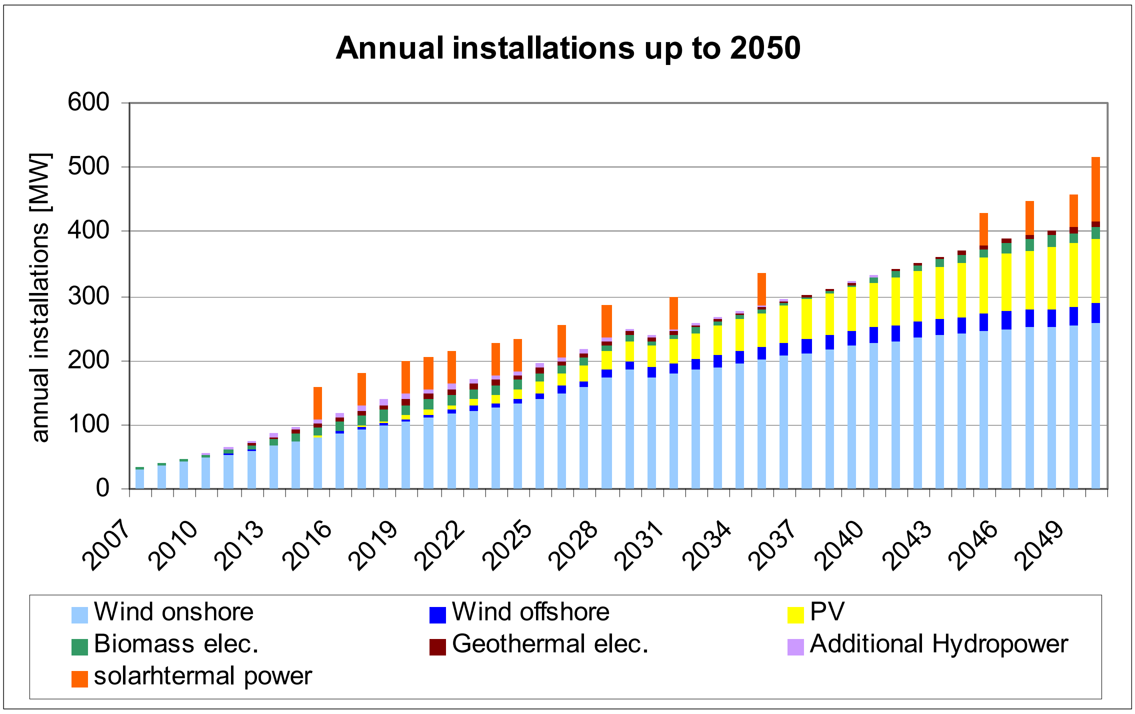
Due to favouring adjustable generating technologies, the share of these technologies at the total renewable generating capacity drops from 2030 to 2050 (see Table 16). Biomass, for example, contributes 7% to the total renewable capacity in 2030 and 4% in 2050. The related development for geothermal power is a drop from 4% in 2030 to 2% in 2050 and additional hydropower's share decreases from 3% in 2030 to 2% in 2050.

This situation is similar for solar thermal power plants – dropping from 13% in 2030 to 7% in 2050, as this technology has much more base load capability than wind energy of photovoltaics, if these plants are equipped with thermal storage systems.

	Installed capacity [MW]		**Share of total capacity [%]**	
	2030	**2050**	**2030**	**2050**
Wind onshore	2,504	5,343	65%	62%
Wind offshore	123	532	3%	6%
PV	224	1,564	6%	18%
Solar Thermal Power	492	596	13%	7%
Biomass elec.	261	320	7%	4%
Geothermal electricity	135	173	4%	2%
Additional Hydropower	115	150	3%	2%
Total	3,855	8,678	100%	100%

Table 16: Climate Protection Scenario, Installed capacities and shares at total renewable capacity, 2030 & 2050

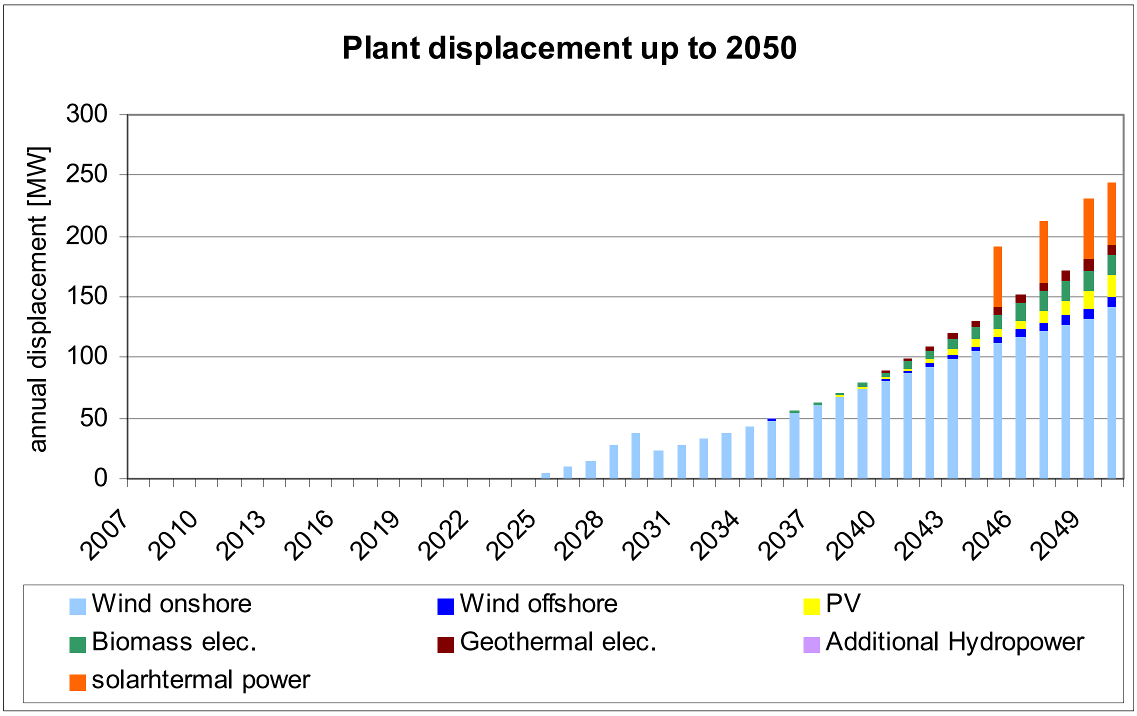
Looking at the annual new installed capacities (Picture 21), a steady growth – up to 2050 – can be observed. By the time around 2030 there is a peak in annual installations, which results from the displacement of wind energy plants that already existed before the development of the scenario starts.



Picture 21: Climate Protection Scenario, Development of annual added generating capacities (including displacement) up to 2050.

While the development up to 2030 is characterized by added capacities, the fraction plant displacement accounts for increases in the aftermath (Picture 22). As a result there is a permanent increase in the gap between the capacity getting installed year by year and the growth in total generating capacity

In 2030 plant displacement exclusively falls upon wind energy (23 MW displaced capacity), with practically no impact on the development of added generating capacities. This situation changes dramatically until 2050. By that time plant displacement increases to 230 MW, which more than the half of the new erected plants capacity in 2050 (455 MW). Consequently the increase in total renewable generating capacity gets reduced to 225 MW in 2050 due to the displacement of outdated plants.



Picture 22: Climate Protection Scenario, Development of plant displacement up to 2050

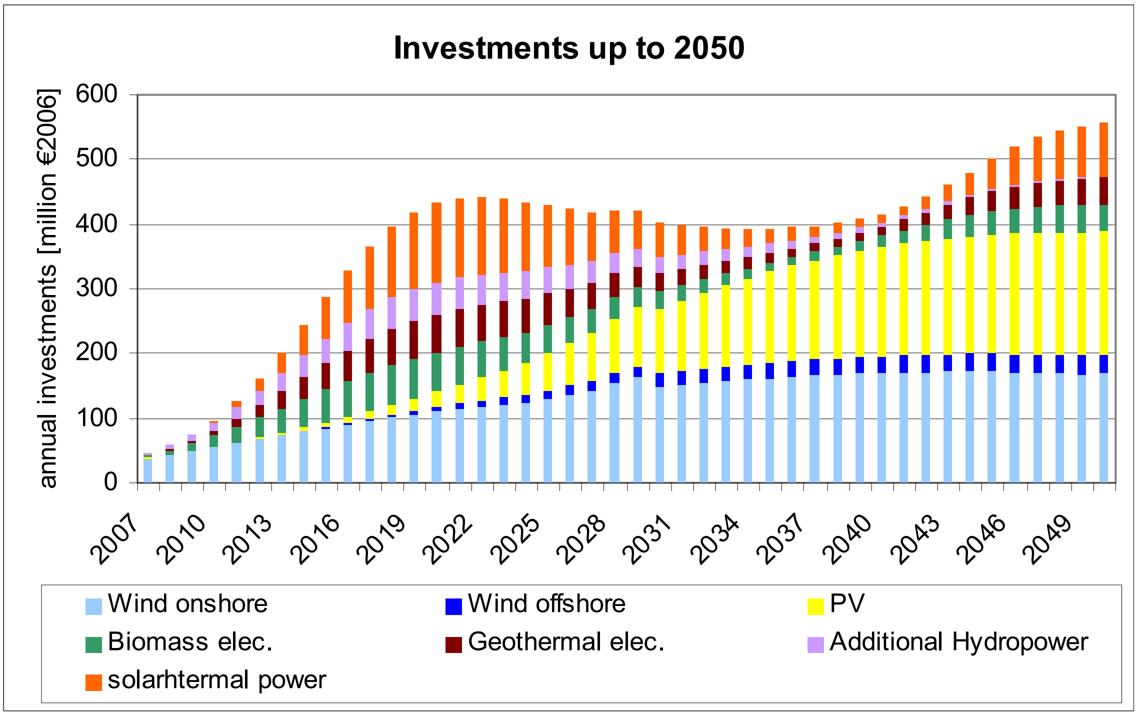
As the relation between added capacities and plant displacement shows that even maintaining the once built up capacities requires a permanent installation activity on a considerable scale, this fact is of huge importance regarding the development of investment budgets.

Provided that there was no decrease in technology costs, this would mean, that the investment would have to remain – with a certain delay in time – on highest level ever seen throughout the whole development, just to maintain the installed capacity.

Fortunately a decrease of technology costs must be expected, with the consequence, that capacity conservation gets cheaper with this reduction in costs. With the costs reductions assumed in this study, the investment budget shows a peak by the end of the considered timeframe (2050). By that time the total investment into renewable capacities is 556 million $€_{2006}$, which is about 85 $€_{2006}$ per inhabitant (see Picture 23).

By 2022 the total investments into renewable generating capacities is 441 million $€_{2006}$ (68 €/cap), which represents an intermediate peak level of investments. Afterwards the budget decrease to 391 million $€_{2006}$ in 2034 (60 €/cap). Beginning from 2034 onwards there anew is an increase to the 2050's level[13].

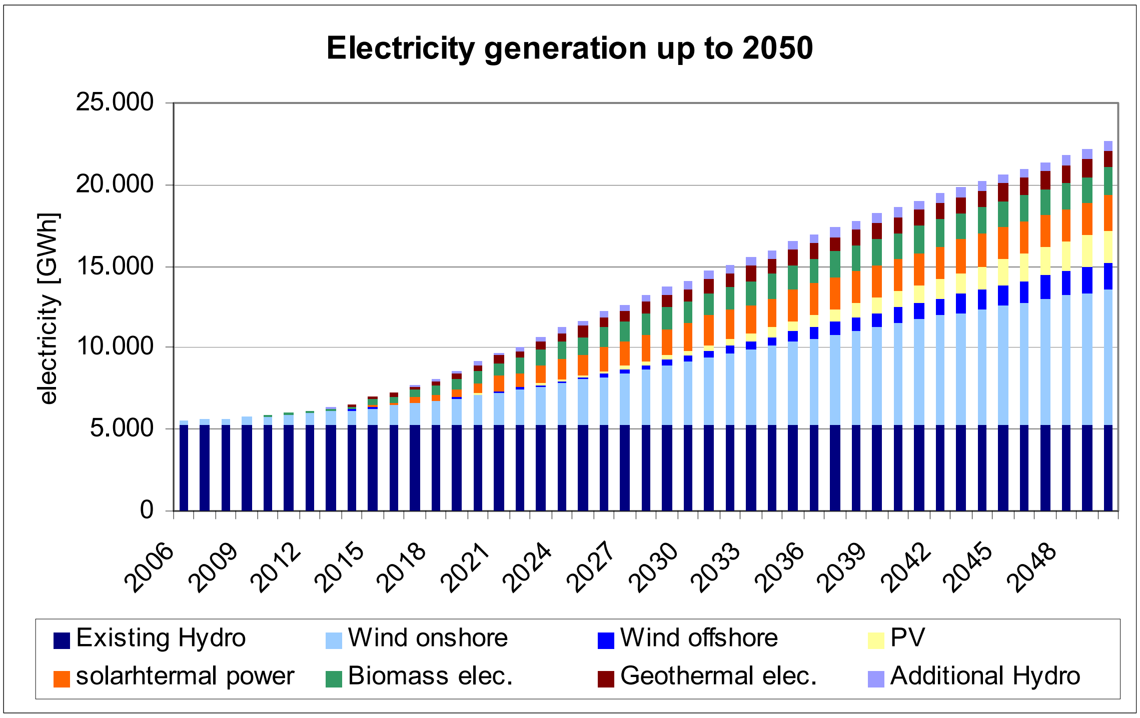
[13] Although the extension of solar thermal power plants happens in blocks of 50 MW capacity each (see Picture 21: Climate Protection Scenario, Development of annual added generating capacities (including displacement) up to 2050.), the investment development does not reflect these blocks. This is due to the assumption, that planning, erecting and financing the plants is distributed over several years.



Picture 23: Climate Protection Scenario, Development of investments into renewable generating capacities

Electricity generation in the "Climate Protection Scenario" (see Picture 24) increases from virtually only the existing hydropower plants contribution (5,300 GWh on average from 2001 to 2003) to 14,250 GWh in 2030 and 22,650 GWh in 2050. Comparing this production figures to the electricity demand projection, as described in the "Energy Demand Module" (23,000 GWh in 2030 and 20,700 GWh in 2050), about 62% of the total Catalonian electricity demand can be covered by renewably produced electricity in 2030. Until 2050 this figure increases to 110%. This excess in covering electricity demand is accepted, as it will help to cope with fluctuations in electricity generation and excesses can be used for exchange with neighbouring regions[14].

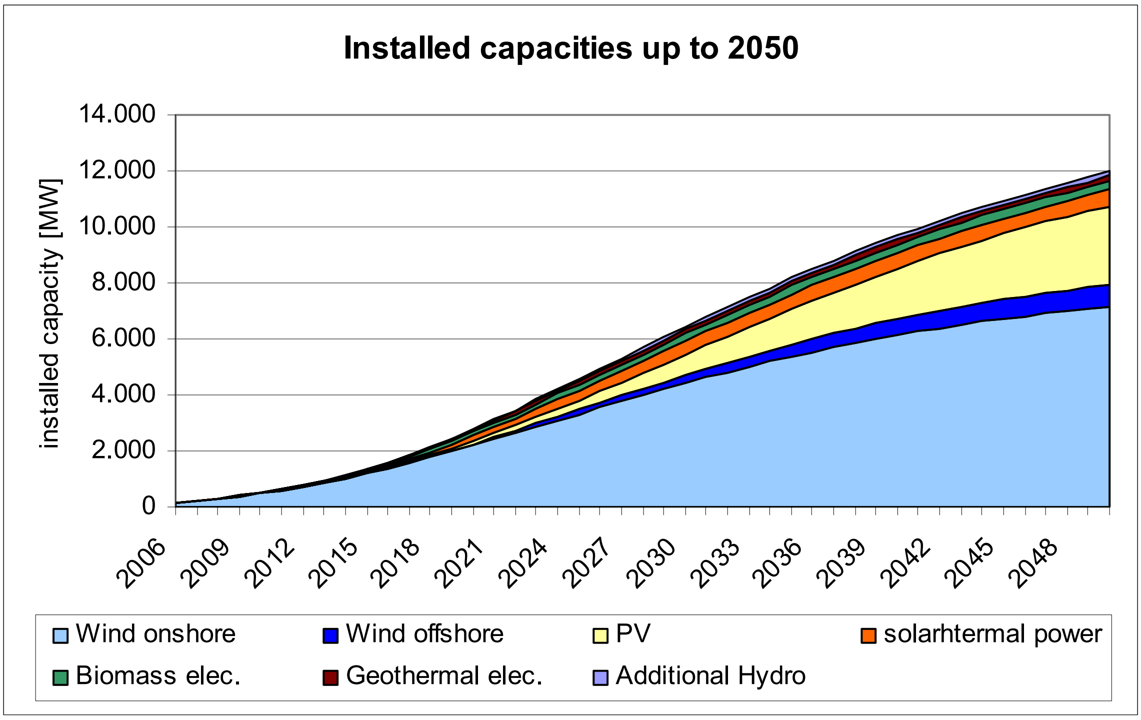
[14] The electricity production in this section is calculated by average annual full load hours, not by simulation using weather data.



Picture 24: Climate Protection Scenario, Development of electricity production from renewables, up to 2050

The "Fast Exit Scenario"

The new added generating capacities of renewables (Picture 20) increases to 6.4 GW by 2030 and further to 12.0 GW by 2050. As with the "Climate Protection Scenario" (CPS), wind energy contribute most to the total capacity, but wind energy's share is even higher in this scenario by 2030 (73% in 2030 and 66% in 2050). Due to the accelerated development, especially for wind energy and photovoltaics, the same can be noted for photovoltaics, with an 11% share in 2030 and 23% in 2050; this is 5% more in 2030 and 2050 than the related figures in the Climate Protection Scenario. The shares of biomass, geothermal, solar thermal plants and additional hydropower are generally lower than in the CPS.



Picture 25: Fast Exit Scenario, Development of installed capacities until 2050

In contrast to the "Climate Protection Scenario", the "Fast Exit Scenario" already shows a decrease in growth as the development approaches towards 2050. This decrease represents the saturation effect of the logistic growth, which occurs due to the fact that installed capacities approach to the limiting potentials.

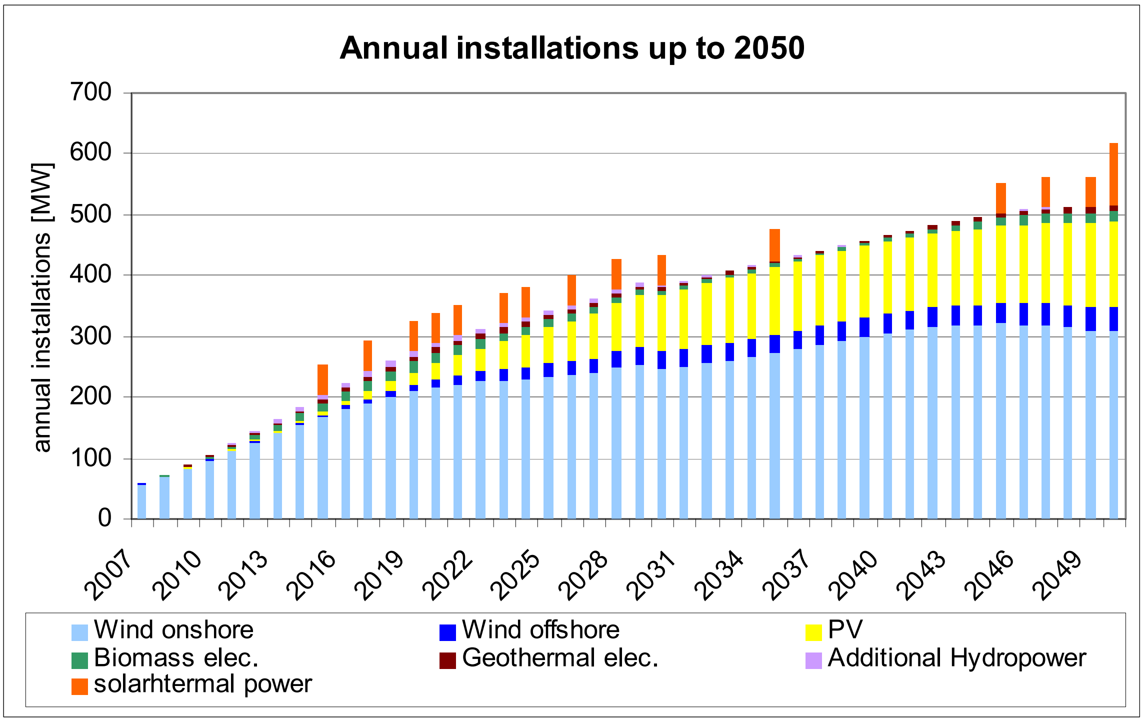
Favouring adjustable generating technologies is less explicit in the "Fast Exit Scenario". Consequently the shares of adjustable technologies by 2030 are already lower than in the "Climate Protection Scenario". Biomass, for example, contributes 3% less to the total renewable capacity in 2030 and 1% less in 2050, if compared to the "Climate Protection Scenario". This relation is similar for solar thermal power plants, geothermal power and additional hydropower.

	Installed capacity [MW]		Share of total capacity [%]	
	2030	2050	2030	2050
Wind onshore	4.412	7.155	69%	60%
Wind offshore	288	778	4%	6%
PV	729	2.803	11%	23%
Solar Thermal Power	492	596	8%	5%
Biomass electricity	261	320	4%	3%
Geothermal electricity	135	173	2%	1%
Additional Hydropower	115	150	2%	1%
Total	6.434	11.976	100%	100%

Table 17: Fast Exit Scenario, Installed capacities and shares at total renewable capacity, 2030 & 2050

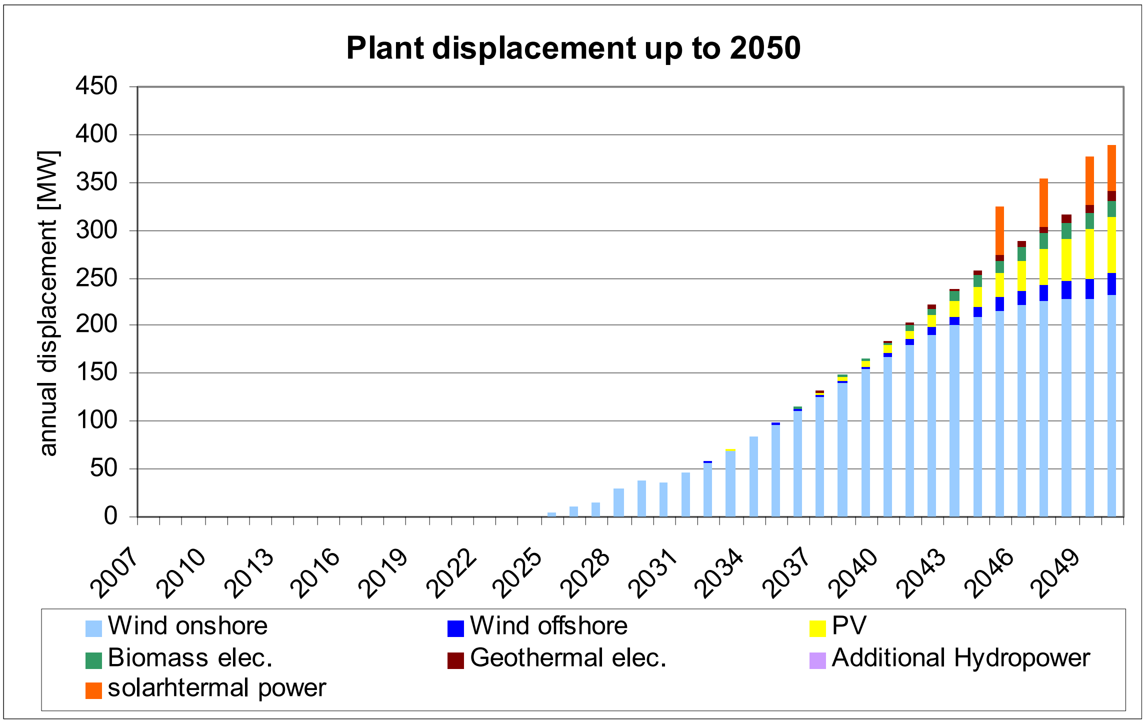
Looking at the annual new installed capacities (Picture 26), annual additions are considerably higher than in the "Climate Protection Scenario. The annual installations by 2030 are already on a scale that is comparable to the additions in 2045 in the "Climate Protection Scenario" (about 400 MW).

The 2050 installation figure is about 500 MW, which is about 100 MW more than in the CPS.



Picture 26: Fast Exit Scenario, Development of annual added generating capacities up to 2050.

In 2030 plant displacement exclusively falls upon wind energy (23 MW displaced capacity), with practically no impact on the development of added generating capacities. By 2050 plant displacement increases to 380 MW, which are about 150 MW more than in the “Climate Protection Scenario”. Comparing the total new installed capacity in 2050 and the fraction the plant displacement accounts for, it can be stated that plant displacement represents almost 70% of the new erected plants capacity, thus reducing the resulting increase in total renewable generating capacity to 30% of the new erected plants capacity (this was 50% in the “Climate Protection Scenario”). As a result only 180 MW of the new built 555 MW in 2050 contribute to an increase of the total installed renewable capacity.

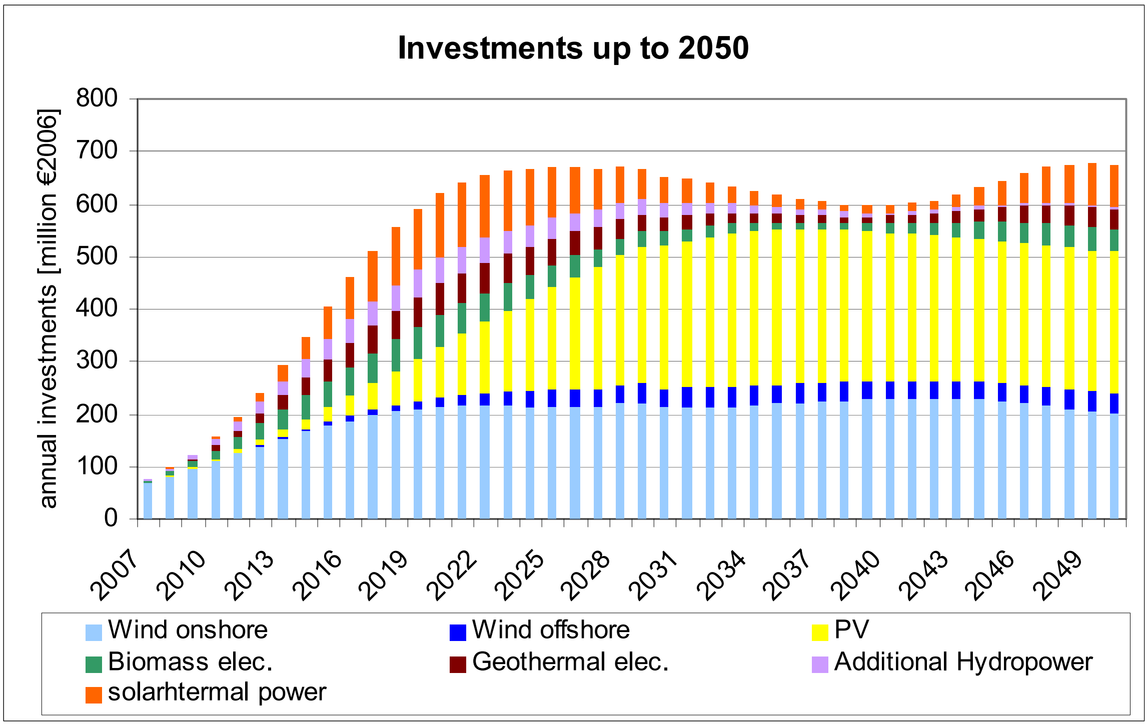


Picture 27: Fast Exit Scenario, Development of plant displacement up to 2050

The investment budget in the "Fast Exit Scenario" shows a peak around 2028. A comparable level of investments gets again reached by about 2050 (670 million €$_{2006}$ in 2028 and 676 million €$_{2006}$ in 2050) [15].

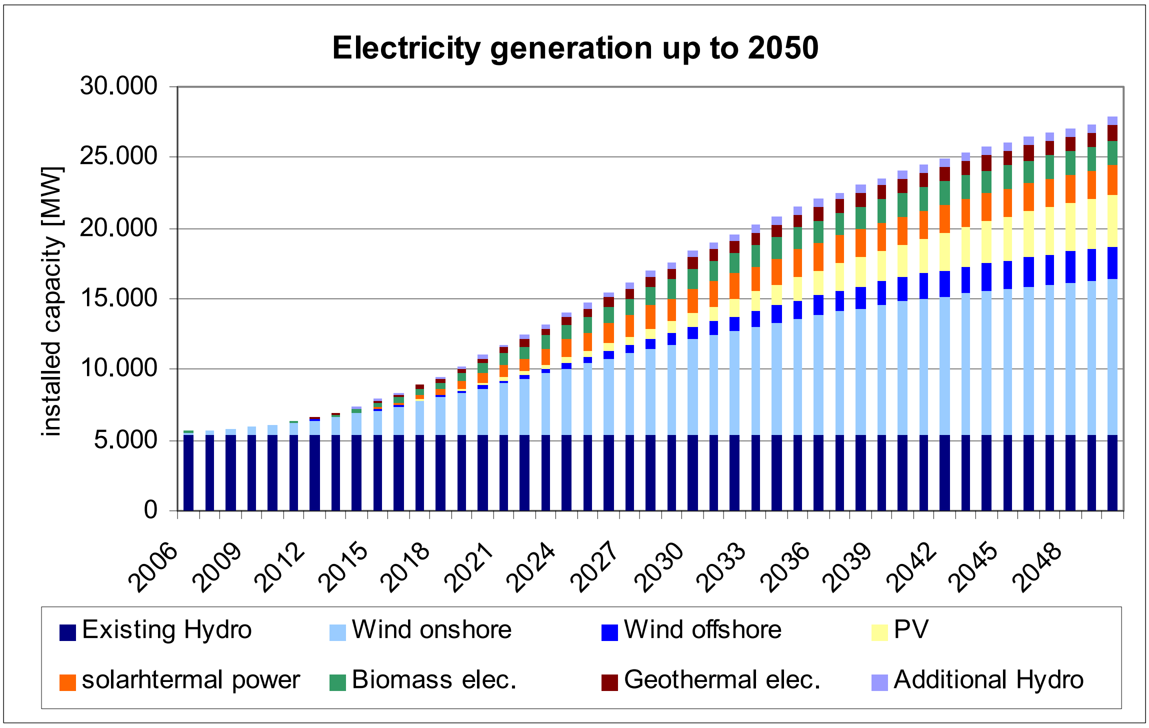
Related to the number of inhabitants in Catalonia this investment figure is equivalent to 103 €$_{2006}$ per inhabitant in 2028 (€$_{2006}$/cap) and 104 €$_{2006}$/cap in 2050.

[15] Although the extension of solar thermal power plants happens in blocks of 50 MW capacity each (see Picture 28: Fast Exit Scenario, Development of investments into renewable generating capacities), the investment development does not reflect these blocks. This is due to the assumption, that planning, erecting and financing the plants is distributed over several years.



Picture 28: Fast Exit Scenario, Development of investments into renewable generating capacities

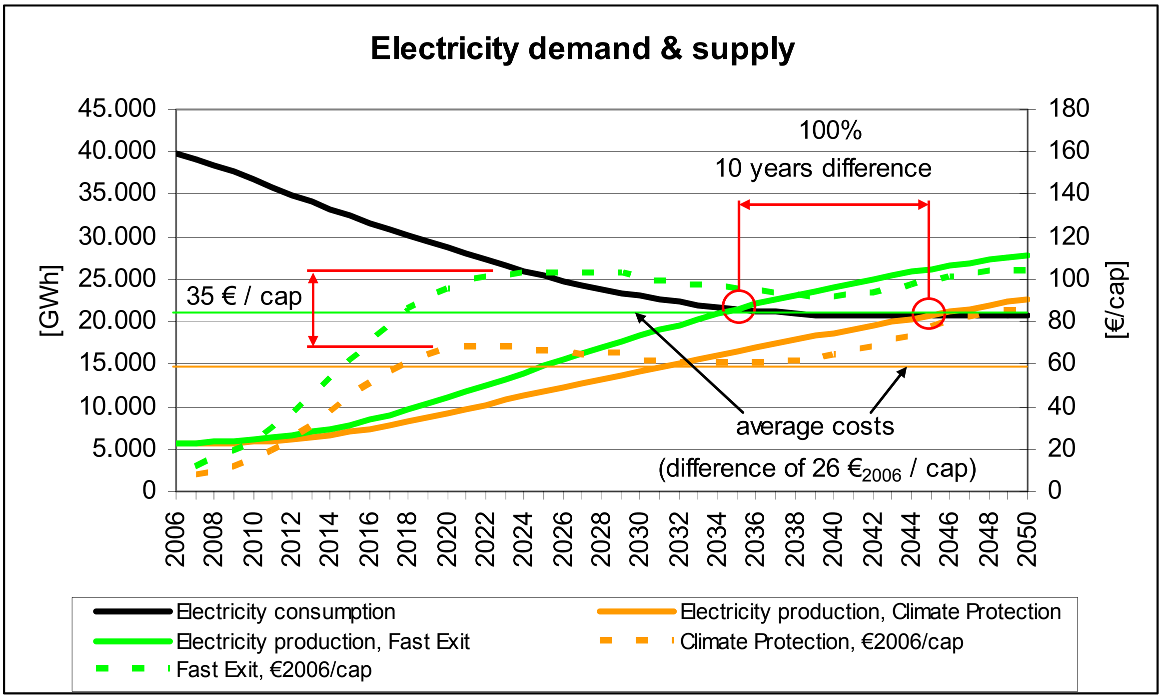
Electricity generation in the "Fast Exit Scenario" (see Picture 29)increases from virtually only the existing hydropower plants contribution (5,300 GWh on average from 2001 to 2003) to 18,350 GWh in 2030 and 27,810 GWh in 2050. Comparing this production figures to the electricity demand projection, as described in the "Energy Demand Module" (23,000 GWh in 2030 and 20,700 GWh in 2050), about 80% of the total Catalonian electricity demand can be covered by renewably produced electricity in 2030. Until 2050 this figure increases to 134%. This excess in covering electricity demand (24 % more than in the "Climate Protection Scenario") is accepted, as it will help to cope with fluctuations in electricity generation and excesses can be used for exchange with neighbouring regions. The further simulation of the Catalonian electricity system will have to clarify, if the greater excess in electricity in the "Fast Exit Scenario" in 2050 does also mean a better grid stability and higher reliability of electricity supply than the 110% coverage in the "Climate Protection Scenario.



Picture 29: Fast Exit Scenario, Development of electricity production from renewables, up to 2050

Conclusion

Both scenarios show the feasibility to achieve a fully renewable supply, one until 2035 (Fast Exit Scenario), the other until 2045. This is not a matter of potentials, but it is a matter of setting and pursuing ambitious goals, encouraging policy and people and – of course – the financial investments Catalonia and it's people are willing to take. The scenarios show that the financial aspect is not that big obstacle that one might expect. With an annual investment into renewable capacities of 104 $€_{2006}$ per inhabitant in the "Fast Exit Scenario" (2050) and $85€_{2006}$ / cap in the "Climate Protection Scenario", the financial burden to achieve a clean a climate friendly electricity supply in Catalonia is moderate in our point of view; in 2030 investments are 103 €2006 / cap in the "Fast Exit Scenario" and 68 €2006 / cap in the "Climate Protection Scenario" (see Picture 30).



Picture 30: Development of electricity demand and supply in the scenarios

These financial figure are only the peak investments during the whole development considered here. Calculating the average annual payments for the two different scenarios result to 58 $€_{200}6$ per inhabitant and year in the "Climate Protection Scenario" and 84 €2006 per inhabitant and year in the "Fast Exit Scenario".

Compared to the Catalonian Gross Domestic Product (181,029 million € in 2005) the annual costs of the scenarios are 0.2 % of the GDP for the "Climate Protection Scenario" and 0.3 % for the "Fast Exit Scenario" on average.

Simulation of Renewable Energy Supply

Coverage and purpose of the simulation

Any energy supply system must guarantee sufficient production and distribution of electricity, heat and fuels to meet the demand for energy at any time throughout the year, usually using different energy conversion technologies. Energy is supplied in the form of electricity, heat or fuels, with heat and fuels having the advantage that both can be stored for later use and can be easily transported. So it is not necessary to consume heat and fuels immediately or directly at the production site. Heat can be stored in thermal reservoirs and distributed via district heating networks. In contrast to heat and fuels, which dissipate with time - thus setting a limit to storage time and distribution distance -, fuels from biomass or hydrogen does not have this limitation in storage time or in transport (depending on the fuel type - solid, liquid or gaseous), but storage losses must be considered too.

The situation is completely different with electricity. The necessity of producing enough electricity, on demand and on time, makes this type of energy the most critical component in an energy supply system. While electrical transport via the public grid is quite unproblematic, storing electricity directly on a large scale is material- and cost- intensive. However, storage in batteries and accumulators can involve the use of toxic substances. Therefore this option is not considered here as it is not appropriate for a sustainable energy supply system. Indirect storage can be used, e.g. pumped hydro-storage systems.

An energy supply system which is based almost completely on renewable sources increases the focus on timely energy provision due to the fluctuating nature of some renewable energy sources, such as solar and wind. Including such fluctuating sources into the public electricity supply means that the power produced by those sources might decrease relatively fast. Of course electricity production from fluctuating sources can be estimated by weather forecasting but a portion of uncertainty still remains. Fortunately, there are other renewable technologies with the ability to deliver energy on demand; hydropower and geothermal power plants give direct access to renewable sources, cogeneration and other energy sources can use fuel from renewable sources (e.g. hydrogen or biomass).

The challenge in designing a highly renewable electricity supply system (up to 100% renewables) is to find the combination where advantages of each renewable source sum up to a functioning and reliable system, while disadvantages are balanced out. Especially in the electrical system the need for reserve capacities, necessary as a back up for fluctuating sources, can be minimised by choosing the right combination of renewable technologies to minimise fluctuations and the introduction of demand management to get a better alignment between production and demand.

In this study we only studied the dynamical behaviour of the electrical system in the scenario "Fast exit". This was done without optimising the electrical energy system. This simulation was done for 4 typical weeks (spring, summer, autumn and winter), with typical weather of the year 2006 [MeteoCat; 2006][16]. The optimization of the supply system and the introduction of modern electrical grid management methods (e.g. Demand Management) will be investigated in a later study.

The SimREN simulation tool

SimREN is a dynamic simulation tool, which calculates the energy supply and demand with a given temporal resolution. As SimREN has a bottom-up structure, the simulated system consists of different elementary blocks that are combined to bigger blocks, which - in total - form the model of the region's whole energy system. An elementary block – for example - could be a single wind turbine and several of them can be combined to form a wind park. These wind parks, together with other energy suppliers and energy consumers, can build a logical region of the whole simulated system. The different energy components yet included in the system are shown in the graph below. The graph also shows the assumed energy flow for a renewable energy system.

The area (e.g. country) simulated with SimREN can be divided into 15 regions, which can exchange energy. i.e. a supply deficit in one region can be compensated by an energy surplus in one or several of the other regions. Even if there is no surplus in any of the regions at the moment, regions can be delegated to increase power production up to their maximum possible production by an energy request from a undersupplied region. An energy manager, which can be set up for different strategies in energy supply, fulfills this task of interregional energy exchange. Each region can be subdivided into ten to fifteen sub regions, each consisting of many different energy suppliers and consumers, with energy suppliers being categorized as fluctuating or adjustable energy suppliers (non-fluctuating).

SimRen uses a database of real weather data and detailed information about the installed capacities of energy producers to calculate the energy output of certain renewable technologies. Typical demand profiles of days for the different seasons - that is the variation of energy consumption in the curse of a day - are a prerequisite to calculate the energy demand throughout the year. A persistent algorithm in the simulation, which calculates the energy demand and supply at every time step, uses this information.

The simulation consists of four parts: First of all the energy demand is calculated. Secondly the electricity production of fluctuating suppliers in every region is determined and subtracted from the energy demand. The remaining demand is what has to be covered by adjustable suppliers and storages, which are last in the simulation sequence. The energy manager is in

[16] [MeteoCat; 2006]: *Servei Meteorològic de Catalunya (*Dades EMA integrades a XEMEC). Department de Medi Ambient i Habitatge

control of the adjustable energy suppliers and keeps track of energy production and consumption in order to properly adjust supply to demand.

Settings of the Simulation

Based on typical electricity demand curves and the assumptions made for the decrease of the electrical demand, we calculated the peak load of Catalonia in the year 2050 to 3,086 MW. Supply Data where taken from the "Fast Exit" Scenario.

Assuming that Photovoltaic will be installed only on roofs of buildings the main installation was done in cities, e.g. Barcelona and its surroundings account for approximately 40% of the total PV installations. The spatial distribution of Wind Energy plants was done by using the sites with good wind conditions and enough space to install them. To simulate the offshore windmills we used modified weather data from "El Perello", a location at the southern coast of Catalonia.

Weather Data Station	MW installed
Roses	1129
Cervera	668
Font rubi	428
El Vendrell	398
Torredembarra	209
Tarrega	334
l'Esplugia de Francoli	932
Castellnou de Seana	568
Vinebre	474
Horta de Sant Joan	469
Mas de Barberans	692
El Perello	854

Table 18: Spatial Distribution of Wind Energy Installation (MW) used in the SimREN simulation; From Fast Exit Scenario 2050.

As the simulation done in the scope of this study has serves the purpose of checking the feasibility of the presented scenarios, no demand or supply management was considered, although we are aware that such measures are helpful in matching energy demand to energy supply and vice versa. Additionally there was no complex optimisation of the technologies distribution to specific locations or the technological composition of the supply system as a whole incorporated into the simulation task. Technical data for all the used technologies are state of the art of today, as we wanted to exclude any kind of speculation with regard to the future development of renewable energy technologies. It is not the case that we do not believe in further substantial progress of the different renewable technologies, but we wanted to stick to conservative path, thus pointing out that all the technologies we need are already there today.

Results of the simulation

The results of the simulation presented on the following pages cover the "Fast Exit" scenario as described in the scenarios section of this study. The simulation was restricted to four week, with one week representing a snapshot for one season of the year. There are no changes with regard to the distribution of the installed capacities, i.e. the distribution is identically to the "Fast Exit" scenario by 2050, although the results suggest that there are options for optimisation, e.g. for minimising fluctuations or a better match of supply and demand and by including storages.

Some major trends can be derived from the simulation results:

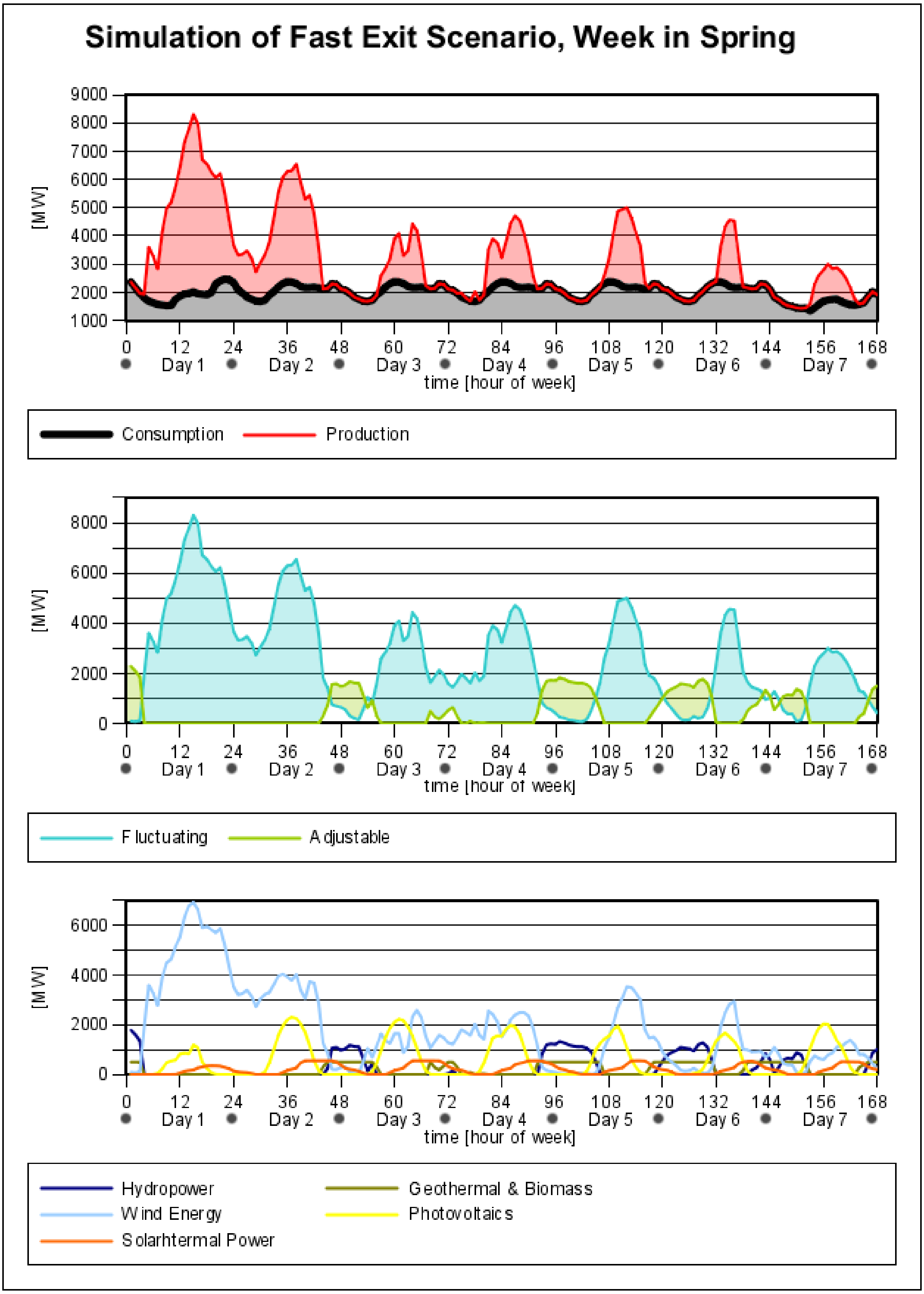
1) Especially during the winter time – a week in January was used for simulation – the adjustable suppliers have to contribute most to electricity supply.
2) During spring and summer – represented by April and July - fluctuating suppliers contribute most to electricity supply, thus hydropower, geothermal and biomass do not have to contribute a lot.
3) In autumn (November) the shares of fluctuating and adjustable suppliers are relatively well balanced
4) Generally spoken there are many times with overproduction during spring and summer. It will have be decided how this surpluses in electricity supply will be handled. Possible options would be optimising the system to avoid these massive surpluses, using excess electricity for storage and/or electricity export, e.g. selling surpluses on electricity markets.

One week in spring

The system dynamics of the spring week (week in April, see Picture 31) is characterised by the production (red line in first graph) exceeding consumption (black line in first graph) by far during many times of the week. Production peaks occur around mid of the days, driven by good solar radiation and wind conditions. At no time demand exceeds production.

Due to the good performance of solar and wind energy, fluctuating suppliers (wind energy photovoltaics and solar thermal power, cyan line in second graph) contribute most to electricity supply, with only minor contributions from adjustable suppliers (light green line in second graph) –which are hydropower, geothermal and biomass - being needed to guarantee that supply meets demand.

The third graph shows the performance of the single supply technologies. One eye catcher in this graph is the strong wind performance on the first two days of the week, which leads to the situation that wind energy production alone exceeds the demand permanently for more than one and a half days. Photovoltaics and wind energy are close together for the rest of the week.



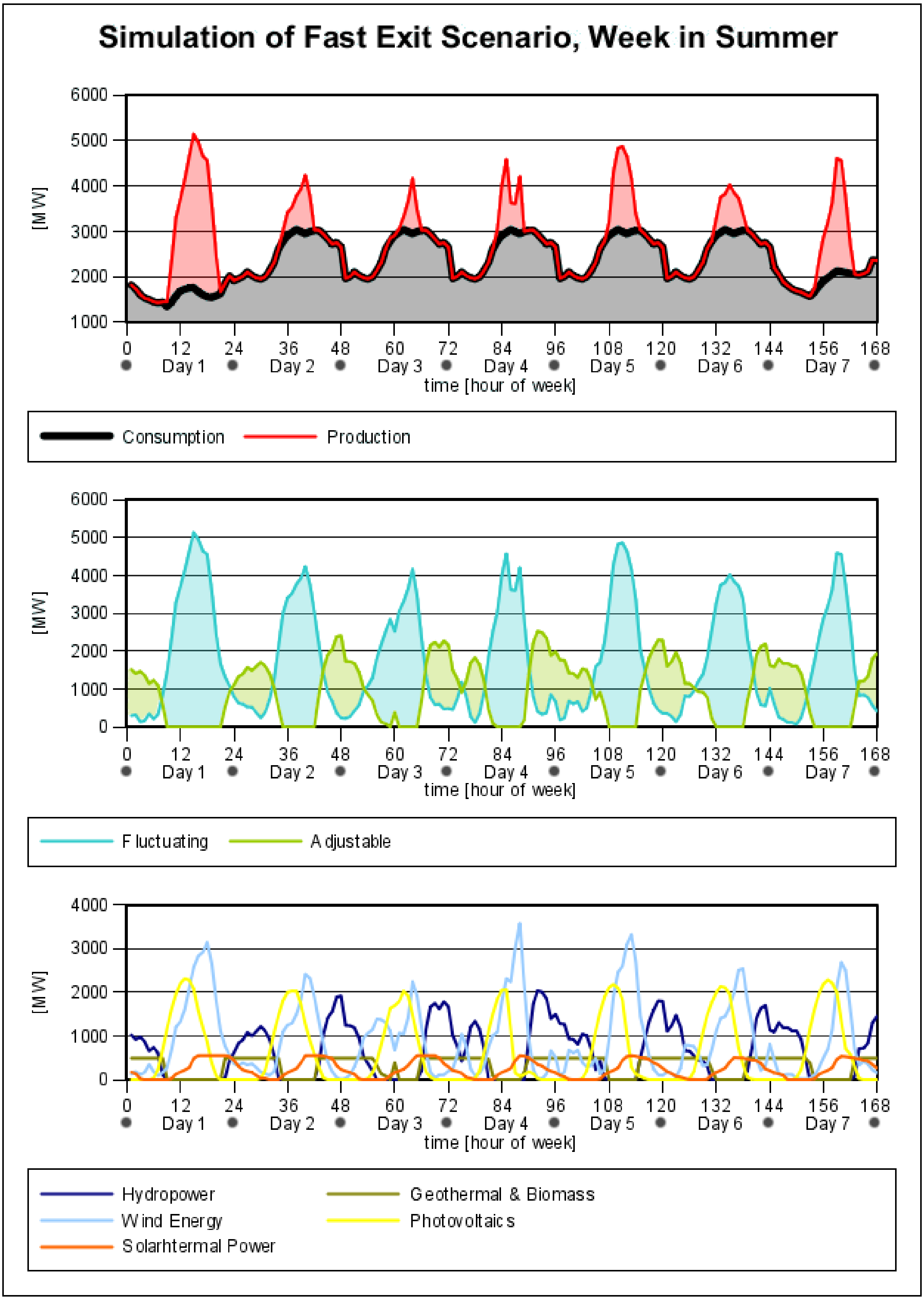
Picture 31: Results of the simulation for one week in spring

One week in summer

During the summer week (week in July, see Picture 32) the demand is generally higher, if compared to the situation in spring. Here again electricity demand can always be fulfilled by the supply system, without production dropping below demand at any time. As in spring. electricity surpluses occur around mid of days, but surpluses are not as often as in spring (see first graph of Picture 32).

Considering the shares of fluctuating and adjustable suppliers (second graph), the fluctuating suppliers still produce more electricity than the adjustable ones. Especially during the nights the adjustable suppliers contribute more to electricity supply than the fluctuating suppliers. This can be explained by the fact that there are no longer periods with constant and good wind conditions and wind speed generally drops during the night times.

The consequence of this lack in wind and solar energy during the nights can be seen in the third graph: while geothermal and biomass are powered up to their maximum production during night, hydropower has to contribute most and must guarantee that demand gets fulfilled.



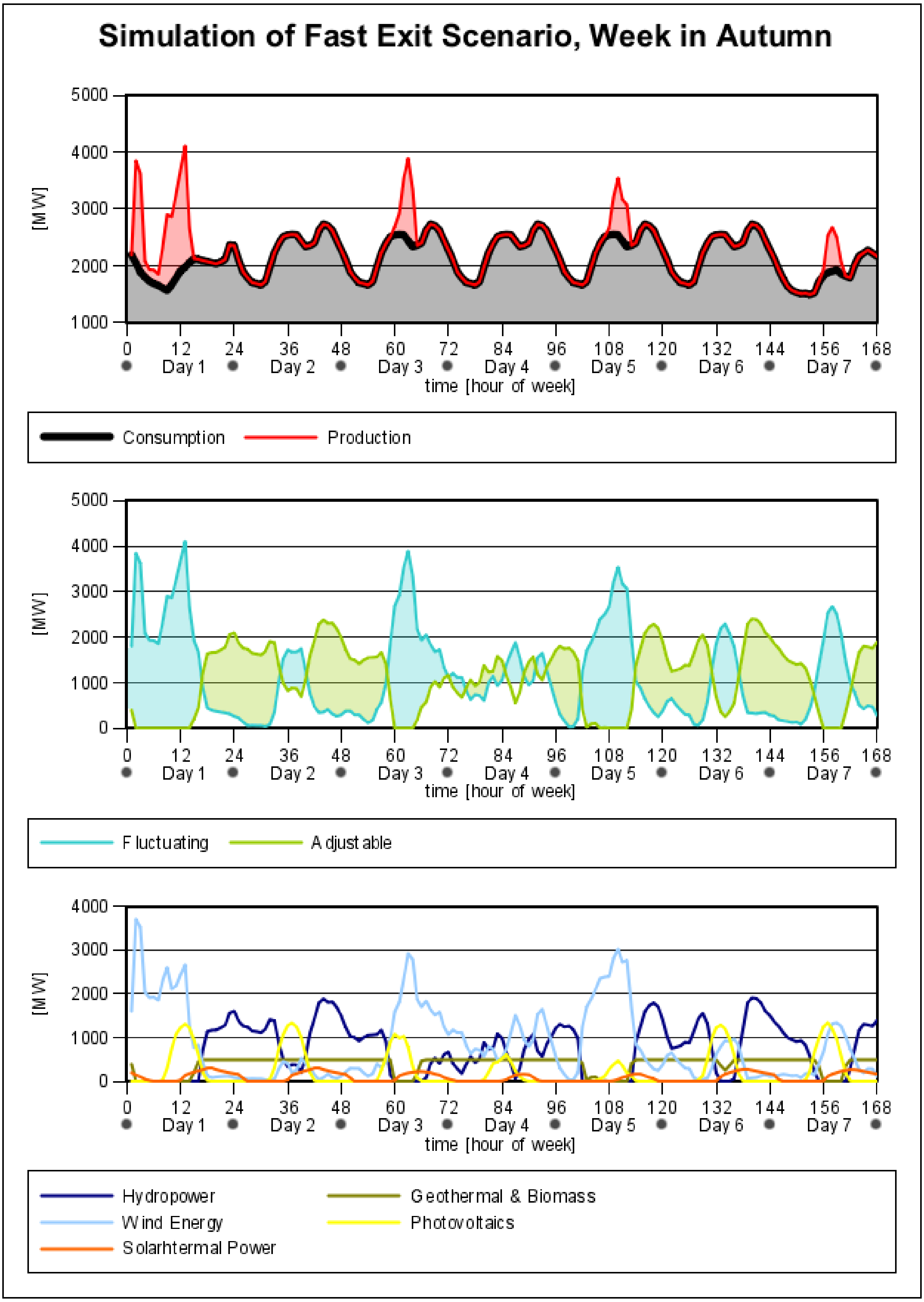
Picture 32: Results of the simulation for one week in summer

One week in autumn

Electricity demand in autumn (November) is slightly lower than in summer (see first graph of Picture 33). Although electricity demand always gets fulfilled, the times with energy surpluses are substantially less than in spring or summer and there are only four days during this week, where production peaks lead to electricity surpluses.

The shares of fluctuating and adjustable supplier are relatively balanced (second graph), but the times when fluctuating supplier alone can supply all the demand are relatively short – with exception to the first day of the week – and this situation occurs only on four of seven days.

Looking at the contributions of the single technologies (third graph) shows that solar radiation has considerably dropped since summer and that wind performance is comparably weak during the simulated week, with almost no wind power on days two and three and peak productions at about 1,000 MW on days six and seven. Consequently hydropower, geothermal and biomass have to make great contributions to satisfy electricity demand.



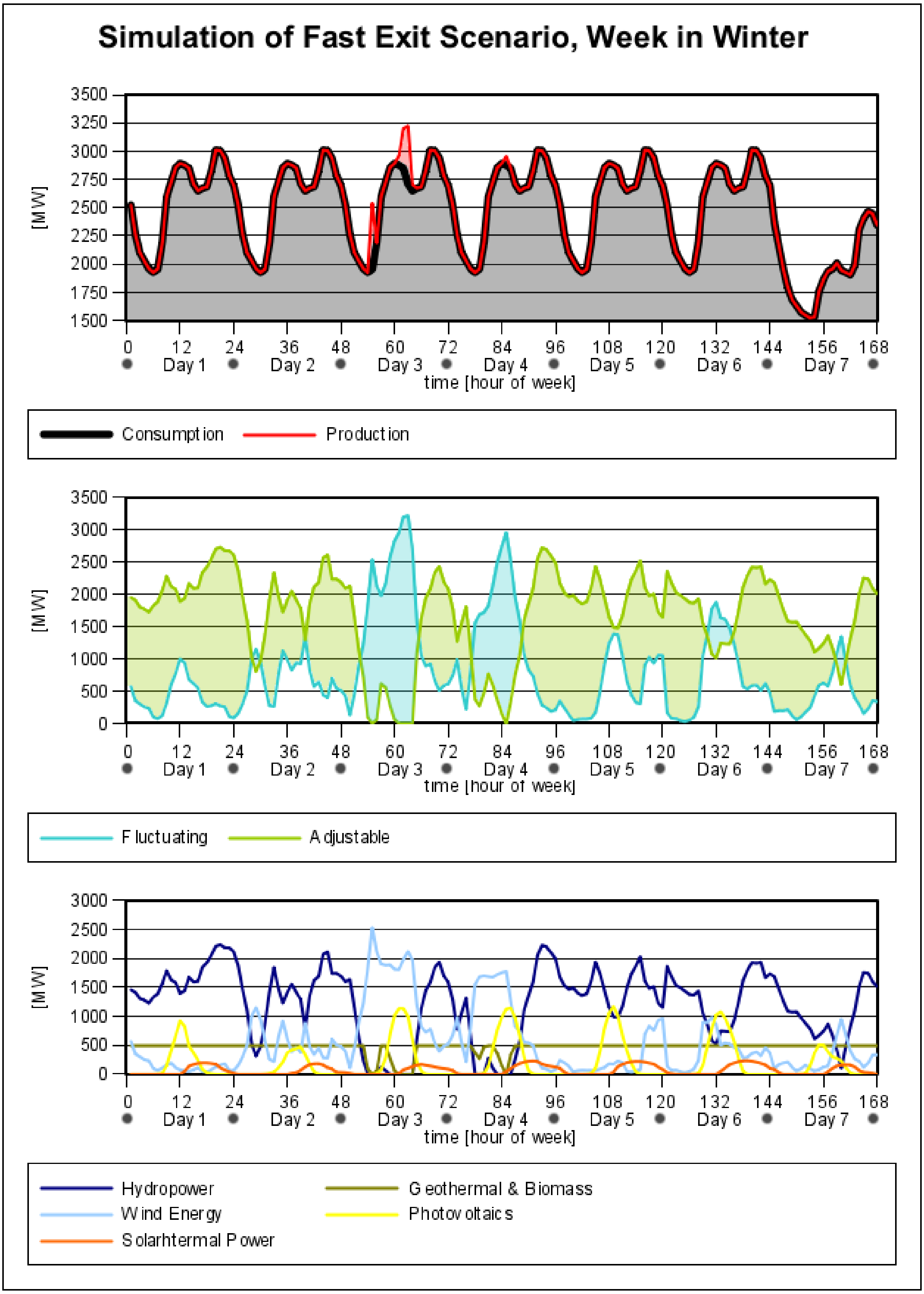
Picture 33: Results of the simulation for one week in autumn

One week in winter

Electricity demand in winter (January) is well comparable to the summer's demand (first graph in Picture 34). Although electricity demand can always be met by production, there is only one day with minor surpluses in electricity supply.

Adjustable supplier are the predominant contributors to total electricity supply in this winter week (second graph). There are only three times, when fluctuating suppliers generate more electricity than the adjustable suppliers, so that the power output of the adjustable suppliers can be reduced significantly.

Although solar radiation is about the same as in autumn, the even lower wind performance requires a heavy utilisation of hydropower, geothermal- and biomass power plants (third graph). While geothermal and biomass plant must be operated at their maximum output for almost the whole week, hydropower has to provide more than 500 MW most of the time, with peak loads in hydropower production going up to more than 2,000 MW. Over more than half of the week hydropower has to deliver more than 1,000 MW, thus making hydropower the main contributor to electricity supply during this winter week.



Picture 34: Results of the simulation for one week in winter

Conclusion

Taking the four simulated weeks as representative for all the four seasons of the year, the supply system according to the "Fast Exit" scenario is capable of supplying all the electricity demand in Catalonia. Generally solar- and wind performance are substantially better during spring and summer than they are in autumn and winter. Due to the strong spring and summer performance of fluctuating suppliers (solar and wind) it is often the case that photovoltaics, solar thermal power and wind energy can supply by far more than the total electricity demand.

During the winter half year the adjustable suppliers are predominant in supply, as the decrease in solar radiation appears in conjunction with generally lower wind speeds. Looking at the big picture the climate variation over the year, with strong solar and wind performance during the warm periods over the year, favours a system as described here, as the adjustable suppliers (hydropower, geothermal and biomass) have to contribute most during those times when they can be operated in the best way. While a high utilisation of hydropower utilisation coincide with higher precipitation levels, geothermal- and biomass plants can mainly be operated during times with a higher demand for heat, thus giving the opportunity to take advantage of high efficient combined heat and power plants.

Policy Module

Energy policy in Catalonia

Catalonia reinstated democratic and autonomous institutions after years of dictatorship, hence the importance we have given to this summary.

Since the reestablishment of the Generalitat in Catalunya and the beginning of the energy crisis, several energy initiatives have been undertaken. These initiatives have been outlined in detail by various Generalitat studies and papers. The *Llibre Blanc de l'Energia a Catalunya* (White Book of Energy in Catalonia, Generalitat de Catalunya, 1981 and 1985) was the first, and was followed by the *ESPREC* programme, *Estudio Especial y Prospectivo de la Energía en Cataluña* (Special and Prospective Study of Energy in Catalonia, CCE; Generalitat de Catalunya, 1989). The *Llibre Verd de les Energies Renovables a l'Euroregió* (Green Book of Renewable Energies in the Euro region, Institut Català d'Energia, 1997) came next and was followed by the *Pla de l'Energia a Catalunya en l'Horitzó de l'any 2010* (Catalonia's Energy Plan Towards the Year 2010, Generalitat de Catalunya, 2002) and the *Pla de l'Energia de Catalunya 2006-2015* (Catalonia's Energy Plan 2006-2015, Generalitat de Catalunya, 2006).

These five documents will be dealt with in this chapter, with a particular focus on the last two. According to them, the critical factors influencing energy forecasts are the economic framework, the social framework (demography, accommodation), energy prices, energy policy and the development of renewable technologies. The environmental aspects and of land and urban planning are also dealt with.

One of the most important concepts to understand in the whole energy system is the chain that exists between the primary energy source and the final energy that is produced (the supply chain). This concept has been developed by Hermann Scheer (Scheer, 2000). The chain includes the materials used for during the conversion process as well as the transportation of energy. In general, the longer the chain, the worse the environmental impact and energy losses. This means it is essential to choose the appropriate sources of energy, technologies used and energy variants in order to reduce as much as possible the supply chain. This supply chain can be greatly minimised by harnessing the sources of renewable energy that Catalunya has at it's disposal.

The White Book of Energy in Catalonia

This document is composed in two volumes (Vol. 1: Situation balance; Vol. 2: The future of energy. Energetic Policy Measures' Plan).It was revised in 1985 and laid the basis for the energy plan proposed by the Catalan Parliament on the 11^{th} of November 1980. It is an important document because it was the first energy plan written after

The speed at which this White Paper was published and the wide range of aspects it covered were made possible thanks to various civil initiatives, especially the "Jornades de Política Industrial i Energètica" (Conferences on Industrial and Energetic Policies, 15^{th} -18^{th} of January 1981). It has to be pointed out that the concern in those years was about reducing energy consumption – principally fuel consumption - and about the effects of local or regional pollution due to energy infrastructures.

The text outlines the following points as objectives for energy policy:

- ensure that demand is met, be flexible and minimize costs in the long term
- favour the simultaneous development of the economy and employment in Catalonia
- encourage the rational use of energy
- favour the knowledge and use of local resources, basically renewable energies in order to reduce exterior dependence and to facilitate the reduction of territorial imbalances
- increase the fight against pollution and strive towards the conservation of the environment This last point is stressed as: *"In all decisions regarding energy policy, the environmental implications will be considered, and the necessary measures will be adopted to minimize possible negative effects."*

<u>Saving and rationalizing the use of energy per sector</u>

- Industrial sector
  - Adapt productive processes in order to reduce consumption, using cleaner forms of energy and developing new and less polluting technologies.
  - Recover secondary resources, especially heat.
  - Create from the Administration, an appropriate energy policy that would advise companies on decision making.
  - Supply information on rationalization and energy saving techniques and devices.
  - Organize research on energy saving technologies.
  - Promote that systems of energy saving are introduced in the studies schemes.
  - Create a database on technical information related to energy.
  - Carry out educational campaigns about energy management.
  - Extractive, producing and energy transforming industries
  - Improve the extracting or energy conversion process
  - Recover valuable secondary energy resources that are created during the process.
  - In the electric sector: undertake actions to "flatten" the charge curve.
- Land and city planning

  - Introduce the energy specific criteria in land and city planning decision making, so that energy efficient infrastructures are created that would allow the use of renewable energy in the future.
  - The location of new urbanisations and the reorganization of existing ones should not generate an excessive rise in transport needs, and should facilitate the use of public transport.
  - The types of buildings, street layouts, plots and other similar measures have to be designed with energy in mind. In particular, they should make use of solar radiation and/or a local energy resource where possible.
  - Seek coordination between organisations in order to identify needs and to achieve efficiency.
  - The public administration will implement a specific programme.
  - Information will be broadcasted; conferences and courses will be organized especially for those responsible for planning..
  - It will have to be decided if it is necessary to establish a specific legislation, especially concerning "the right to the Sun".

- Domestic, service and primary sectors
  - It is necessary to direct the domestic sector towards rationalizing objectives.
  - The pricing policy should be coherent with other energy policy objectives.
  - The information and subsidies should be provided in such a way that the decisions will be taken rationally and the most convenient sources of energy will be used.
  - A set of standards should be established, regarding buildings, domestic appliances and heating devices.
  - The correct fulfilment of standards regarding the building's thermal isolation will be subject to the necessary control measures.
  - Information will be broadcasted to individuals, companies belonging to that field, architects, quantity surveyors and builders.
  - Public information campaign will be carried out so that energy criteria will be taken in consideration when buying or renting a flat, or acquiring appliances.
  - A "refurbishig" campaign will be carried out in the public sector, by undertaking the necessary improvements and establishing the appropriate control measures.
  - New buildings will have to be designed and built to be models of rational use of energy.
  - Maximum coordination between public bodies will be aimed for, in order to detect needs, and accomplish efficiency.
  - A common standard for energy accountancy will be established, to permit the knowledge of and comparison between the energy consumption of different public entities. This will permit the estimation of the possible rationalization of the use of energy.

- Transport sector
    - To be the priority sector in energy policy, given the importance of its consumption and share of oil products.
    - Decrease energy consumption in the transport sector.
    - The less consuming models and the improvements that permit reducing the consumption will have to be introduced quickly.
    - The municipalities should receive financial support to improve the characteristics of public transport, especially regarding mobility and speed, and to create the necessary additional nets.
    - In big cities particularly, the use of individual vehicles should be reduced.
    - The use of trains should be promoted for transportation between cities.
    - An effort to use the most efficient means of long distance transport.
    - Information will be broadcasted about the energy consumption of different transport methods. Campaigns and trainings will be carried out for drivers and entrepreneurs about more appropriate ways of driving.
    - A campaign will be carried out to promote an increase in vehicle occupation rate.
    - At public level, the necessary technical improvements will be introduced, as “model policy”.

- Electric sub-sector
    - Conversion to CHP of two fuel-oil power plants
    - Respond to electric demand through tariffs and industrial localisation policy in order to flatten the consumption curve and reach a more uniform consumption pattern
    - Promote cogeneration.
    - The electric tariffs will have to reflect the real costs in order to favour energy saving and the appropriate allocation of energy resources.
    - The Catalan Landing Plan will plan the locations for the installation of the new means of production, transport, transformation and distribution of electricity.
    - The necessary studies on environmental impact will be carried out to assess the locations for new production plants.
    - The different measures about nuclear plants and radiological controls mentioned in this document are not to be added in this section.

- Oil sub-sector
    - Replacement, in the generation of electric energy, of fuel by nuclear energy and coal, and in the industry, replacement of fuel by coal.
    - In the domestic sector, the proposal is to replace oil production by natural gas.
    - Application of energy saving policies, and introduction of renewable energies to moderate oil consumption.

- The necessary measures will have to be taken in order to reduce the risk of accidents related to the production and manipulation of crude oil. In case of an accident, the appropriate installations and devices shall be ready to take action, so that undesired consequences on the environment of the Catalan coast can be avoided.

- Gas sub-sector
  - Extend the nets of natural gas transport and distribution and establish a fiscal and price policy that shall allow the penetration of pipe-line gas into Catalonia, and make it possible for gas to compete with the combustibles it shall replace.
  - In the industrial field, it will be necessary to favour a significant introduction of gas in the long term.
  - The use of natural gas in thermal plants shall be reduced to the needs of regulation of the gas system and to reduce effects of the installation on the environment.
  - A proposal shall be made to the Central Catalonian Government for a set of rules about natural gas and manufactured gas producing and stocking installations, similar to that which exists in other countries.

- Coal sub-sector
  - It seems necessary to favour the increase of coal consumption in Catalonia. This increase shall be accomplished by raising the production of local coal and imported coal.
  - It is necessary to know in greater detail the amount of remaining coal reserves in Catalonia.
  - At state level, a price policy will have to be established that would cover the real exploitation costs by mining area. This price policy should favour the exploitation of national coal and if necessary, the difference with this and the imported coal will be covered by state subsidies.
  - Political guidelines shall be established for the defence of the environment. These should not vary constantly, and should take into account the ecological needs, the interests of the energy policy, and competitiveness. These guidelines should cover the whole coal cycle, from extraction to final consumption.
  - Research on the use of coal in industry shall be promoted. Possible consumers should receive information about the coal market and the existing technologies for the use of coal.
  - The Catalonian Landing Plan will plan the location of the necessary installations for the importation, stocking and transportation of coal.
  - It will be requested that the Central Administration will promote legislation about ecological protection to avoid negative consequences on the mining environment.

Renewable sources of energy

  - It is extremely difficult to analyze the role of the renewable energies in the future energy supply; most are not technologically developed, or are not economically profitable.
  - The evaluations presented here are not based on objectives to reach, but on reasonable speculations about the future based on the information available nowadays.
  - The need to diminish energy dependence and to protect the environment justifies the interest of favouring the development or implementation of certain technologies in order to take advantage of renewable energy resources.
  - The development of these resources is highly desirable.
  - The Industry and Energy Department will be responsible for facilitating the introduction of these technologies into the market.
  - There will be a proposal for the creation of an organism that shall favour renewable energies, energy saving technologies, and the rational use of energy, in a year's time.

- Solar Energy
  - Applying solar energy means in the mid to long term, adaptation of city and land planning, so that it is possible to access solar radiation and the buildings take maximum advantage of this energy.
  - In order to increase the speed of market penetration, the use of theses technologies will be promoted in the fields where it is easier to implement, and in the public sector.. This will be done through a plan for the introduction of solar energy.

- Biomass
  - The possibilities of recovering "residual biomass" will be studied. This could be done through a plan for the use of biomass that should be designed in 18 months time.
  - The guidelines for the management and exploitation of the forests will be defined in that plan.
  - A proposal will be done for the standardization of the classification of bio- fuels.
  - Research on the processes of biomass valorisation will be carried out, as well as educational exhibitions.

- Micro hydraulic power generation
  - The current situation leads us to take advantage of any resource that could represent an energetic plus, even if it is not very significant.

- Wind energy
  - The concrete actions in this field are directed to promote the use of small aero generators, to establish the necessary control and quality mechanisms, and to obtain enough data to evaluate the Catalan potential in wind energy.
  - The Industry and Energy Department will provide the information about the possibilities of using wind energy, and about the existing grants and subsidies.

The manufacture of wind generators by Catalan industry will be promoted.

- Geothermal energy
  - To facilitate on-going research and ensure its continuity until the potential of this energy resource in Catalonia can be determined.
  - In the case that geothermic energy is more profitable, necessary legal and financial measures will be put in place to take advantage of this resource.

ESPREC Program – Study of Energy in Catalonia

Local policy

- To add energy criteria to urban planning and land management.
- To promote rational energy management. To promote exhibitions in the field of efficient technologies and renewable energy use.
- To add energy infrastructures in planning.
- To promote the coordination between the development of infrastructures and maintenance.

Regional Policy

- To contribute to the improvement of the energy sector.
- To promote the quality of energy suppliers.
- To participate in planning and defining energy policies at a national level.
- To make an effort to improve energy efficiency.
- Promotion of efficient technologies as cogeneration.
- To maintain the effort in promotion of renewable energies.
- To promote public consciousness on energy issues.
- To devote enough human resources to plan an energy system with new technologies and renewable energies.

Country policy

- Fuel Sector
  - To reduce fuel dependence and consequently fuel imports.
  - To reduce environmental impact of transformation facilities.
  - To improve efficiency and security of transport and distribution of fuel products.
  - To reduce the environmental impact that is associated with the consumption of fuel products.
  - To promote saving of fuel products.

- Carbon Sector
  - Reorganization of the carbon sector.
  - To maximize the use of national carbon.
  - Implementing techniques to minimize environmental impact.

- Gas Sector
  - Integration in the European net of gas pipelines.
  - Diversification of supplies.
  - Expanding pipeline coverage.
  - Building short term European connections
  - Similar financing treatment for pipelines than for other transportation infrastructures.

- Electricity Sector
  - Reduce the debt of the electric sector.
  - Reduce the environmental impact of cogeneration plants.
  - Improve the supply quality.
  - Improve access to the electric net. Rural electrification.
  - Business rationalization in the sector.
  - Solution for the activities related to the third phase of the nuclear cycle.
  - Lengthen the useful life of the existing generating park.
  - Promote electricity saving.

- Cogeneration
  - Adapt the tariff structure.
  - Increase the generating park.

Green Book of Renewable Energies in the Euro region

The use of renewable energies entails certain environmental, social and economic benefits, although generally, they are not considered in energy structures.

Some benefits ascribed to the use of renewable energies are: the reduction of CO_2, the use of local resources, the protection of nature and land preservation.

Nowadays, the market of the renewable energies makes the Euro region, an exceptional region for a future development.

The Euro region has the capacity to achieve 15% of the primary energy demand of renewable energy before 2010 and to double, with the exception of hydraulic power, the production of renewable energies in 2005.

The obstacles related to the consolidation of renewable energies are the lack of specific elements to favour them in the energy market.

It is necessary to take into account that the next two decades are very important in a transition to a sustainable development model and that renewable energies are an important factor in reducing fossil fuel dependence.

Renewable Energy Policies in Catalonia

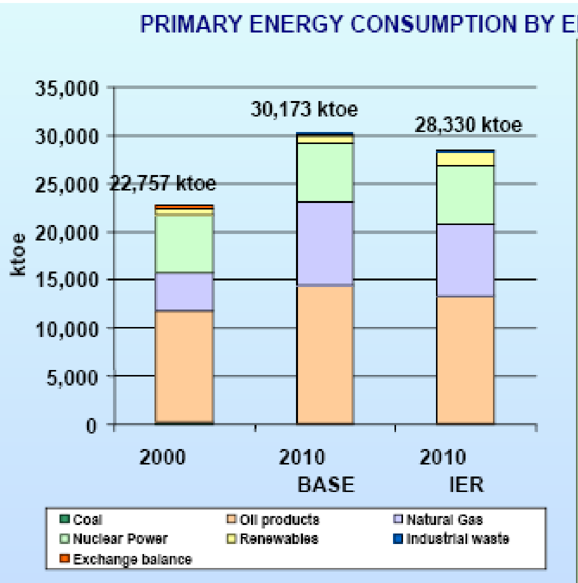
Since 2000, the Catalonian Government has developed two energy plans during in different politic periods. The first energy plan was developed targeting the year 2010 and was the basic strategy document on energy policy of the Government of the Generalitat of Catalonia (center-rigth oriented). In 2005, the new government (left oriented) presented the "Catalonian Energy Plan: 2006-2015. This second plan intended to be a pick-up point for a new energy model although finally, the two plans are quite similar.

Catalonia's Energy Plan Towards the Year 2010

In response to the Parliament of Catalonia demanding the Government of Catalonia to prepare a strategic energy plan, an efficiency plan and a renewable energy plan where developed. The aim of the plan was clear: to favour Catalonia's economic growth and social enhancement in order to get closer to European standards.

This plan has 5 strategic priorities:
1. efficient management of energy demand;
2. a friendly use of the environment;
3. to improve energy supply in Catalonia;
4. to deepen in the improvement of energy markets;
5. to take catalan energy policy to the highest strategic level.

The following table shows how the plan foresees the primary energy consumption by energy sources 2000-2010 in 2000 and in two different scenarios in 2010 (BASE and IER).



Mean yearly growth rates in the period 2000-2010 (%)

Energy source	BASE Scenario	IER Scenario
Coal	-12.2%	-13.0%
Oil products	2.2%	1.4%
Natural Gas	8.4%	6.7%
Nuclear Power	0.1%	0.1%
Renewables	3.1%	9.4%
Industrial waste	8.8%	8.8%
TOTAL	2.9%	2.2%

Percentage with regards to total amount (%)

Energy source	2000	2010 BASE	2010 IER
Coal	1.2%	0.2%	0.2%
Oil products	50.9%	47.7%	47.0%
Natural Gas	17.0%	28.8%	26.2%
Nuclear Power	26.3%	20.0%	21.3%
Renewables	2.7%	2.8%	5.4%
Industrial waste	0.3%	0.5%	0.5%

Picture 35: Primary energy consumption in Catalonia by sources, 2000 – 2010. [CEP; 2005].

The main objectives in energy efficiency and renewable energies of this plan are:

Main objectives of the Energy Efficiency Plan:

- Energy intensity improvement: 1.3% per year
- Saving 1,579 ktoe in 2010
- Setting up 861 additional MW in co-generation plants in the period 2000-2010.
- Investments in the range on 2,947 M€ related to the Energy Efficiency plan.
- The Energy Efficiency Plan overcomes the objectives of the "ActionPlan to Increase Energy Efficiency in the European Union"(COM (2000)247, since the European objective envisages a yearly improvement of energy intensity at 1% up to 2010.
- Likewise, the participation of cogeneration in the gross production of electricity is higher that the 18% set for the whole European Union in the European Action Plan.

Main objectives of the Renewable Energy Plan

- Additional production of 904,400 toe in the period 2000-2010, until reaching 1,527 ktoe in 2010 (145% increase) with the Renewable Energy Plan
- Participation of renewable energies in primary energy consumption of 5.4% in 2010. Participation is doubled if compared to that in 2000 (2.7%) in agreement with European Union objectives.
- The Renewable Energy Plan proposes to rationalise a very high percentage of Catalonia's current economic and technical potential in each renewable energy sources.
- Investments in the range of 1,743 M€ related to the Renewable Energy Plan and 1,869M€ for all renewable energy facilities.
- The contribution planned in Catalonia by the Spanish Renewable Energy Promotion Plan, prepared in 1999 by the IDAE is 1,258 ktoe, in comparison to 1,527 ktoe envisaged by the present Energy Plan and, therefore, it accounts for an effort that goes beyond 21% the plans made by the Promotion Plan, the participation of renewable energies in primary energy consumption in Catalonia would only by 4.4%

The budget was fixed in 12,000 M€, with 40% assigned to renewable energies and energy efficiency.

It is important to take into account this energy plan to understand why the second plan could have been better.

Energy Plan for 2006-2015

The Catalonian Government has developed an Energy Plan for the horizon 2006-2015 trying to reach a new energetic model based on sustainable development. This new initiative has 3 principles: saving and energy efficiency, renewable energies and quality of energy supply. Catalonian energy policy would like to develop by means of:

- increase of energy knowdledge

- promote saving and energy efficiency
- promote the use of renewable energies
- develop energy infrastructures to ensure energy supply.
- support research and energy technological innovation.

The main objectives in energy efficiency and renewable energy are:

Main objectives of the Energy Efficiency Plan:

Qualitative:

- Reduction of inefficiencies and unnecessary consumption in Catalonia, to the level that is technically, economically & socially possible with an effective management of resources.
- Correction of the course of the last few years.

Quantitative:

- Savings of 2,138 ktoe in 2015 (10.6% with respect to the base scenario) and of a total of 9,433 ktoe for the 2006 to 2015 period. Savings objective also higher to that of the present European Directive proposal on energy efficiency, that sets a 11.5% savings objective over the average final consumption of the last five years, while the Plan's objective represents a 14.6% saving.
- Energy intensity improvement of 1.74% per year in the 2006-2015 period, which is beyond the 1% per year of the Action Plan to Improve Energy Efficiency in the European Union COM(2000) 247.

Main objectives of the Renewable Energy Plan

It proposes to develop renewable energies until the tecnoeconomic roof. The problem is that the potential is much more than the maximum stated in the plan so the renewable energy policy could be better.

The assigned budget is 10,000 M€.

2003			2010			2015		
Description	**product. (tep)**	**%**	**Description**	**product. (tep)**	**%**	**Description**	**product. (tep)**	**%**
Wind								
86.7 MW	14,026	1.9	3,000 MW	642,086	30.9	3,500 MW	757,954	25.7
Solar (photovoltaic)								
2.2 MW installed	168	0.0	50 MW	5,094	0.2	100 MW	10,213	0.3
Solar (thermoelectric)								
0.0 MW installed	0	0.0	50 MW	12,040	0.6	50 MW	12,040	0.4
Solar (thermal)								
39,600 m2	2,731	0.4	730,000 m2	50,363	2.4	1,250,000 m2	86,050	2.9
Hydroelectric								
2,320.2 MW	430,047*	58.4	2,376.8 MW (55.6 MW new in RE)	484,791	23.3	2,474.8 MW (153.7 MW new in RE)	528,041	17.9
Biogas								
24.5 MW for electricity production + thermal uses	22,724	2.8	96.3 MW for electricity production + thermal uses	162,609	7.8	120.2 MW for electricity production + thermal uses	205,570	7.0
Biofuels								
6 kton biodiesel production + 20 ktoe bioethanol (ETBE)	25,287	3.4	8% of the demand for gas oil with biodiesel + bioethanol (ETBE) in all petrols	377,663	18.1	18% of the demand for biodiesel gas oil + bioethanol (direct mixture & ETBE) in all petrols	844,095	28.7
Biomass (woods)								
Direct thermal uses + 0.5 MW for electricity production	93,906	12.7	Direct thermal uses increase by 19.2 ktoe + 26.0 MW for electricity production	180,912	8.7	Thermal uses increase by 50 ktoe + 63.7 MW for electricity production	306,570	10.4
Renewable waste								
45.2 MW in RSU	147,712	20.1	45.2 MW in RSU + 19.9 ktoe of sewage sludge for thermal uses	166,700	8.0	45.2 MW in RSU + 52.0 ktoe of sewage sludge for thermal uses	198,781	6.7
Total Renewable Energy								
736,601 toe			2,082,259 toe			2,949,313 toe		
RE share of primary energy								
2.9%			6.9%			9.5%		
RE share of primary energy excluding non-energy uses								
3.3%			7.9%			11.0%		

Table 19: Sector objectives envisaged by the Renewable Energies Plan

Comments on the Energy Plans

The plan itself praises its ambition in Renewable Energies in Catalonia because of the supposedly low potential on renewable energies. However, the real potential of renewable energies in Catalonia is much more. For example, the wind potential stated in the plan is 5,000MW and, following Greenpeace Report "Renovables 2050", the wind potential is more than 70GW.

Catalonia has a big capacity to generate energy with renewable energies and it is not taken advantage in the plan in force. It would have been possible to write a plan with accurate actuation and not a general plan with general lines. The new plan has not solid objectives related to saving, efficiency and renewable energies and since a new plan was written, more concrete objectives could have been proposed.

Comparing the two plans it is possible to see that there are no significant differences in quantities. In both plans two scenarios are established: the first one is the "base scenario" that shows the tendency without applying the strategy and the second one is the "intensive scenario" that applies saving, energy efficiency and renewable energies following the strategy. Comparing values for each scenario and each plan, it is stated that the values are quite similar what means that the second plan has not improved the other. To sum up, write plans without binding endorsement is not the way for a competent energy policy.

Policy Measures to support the scenario goals

However, economic, legal and institutional conditions for the energy system must fundamentally change and indeed, this must happen soon. In practice, we will need to rely on a mixture of instruments and measures. In addition to what is described and planned actually in Catalonia, we think that additional efforts have to be done to realize a sustainable energy future.

General political measures:

- Adoption of a set of rights and responsibilities that guaranty the democratisation of the energy systems (see below)
- Development of a land use plan for renewable energies, based on a more realistic picture of Catalonia's renewable energy potentials,
- Establishing preferential areas for wind energy, according to the potentials and locations described in the scenarios section.

- Reassessing and restructuring the use of coastal areas for offshore wind energy, focused on the best locations, as described in the scenarios section.
- Setting up an energy supply regime that favours renewable technologies as the first option whenever a new plant should be built.
- Primacy of cogeneration over conventional thermal power plants, combined with biomass and geothermal use being the first choice.
- Priority on using pumped hydro plants to support and compensate fluctuating suppliers,
- Long term electricity price guarantees for new erected renewable energy plants and permanent review of feed-in tariffs for the different technologies in order to keep the installation stimulus on a sufficient and technologically well diversified level,
- Starting a "green Government" initiative in public buildings and public services, with the improvement of energy efficiency in public buildings, with the incorporation of local energy generation and the replacement of car fleet by most efficient vehicles, with priority to biofuels, etc.),
- Adopting energy efficiency standards for all electrical artefacts, with priority to lighting bulbs and appliances (e.g. all electrical appliances must meet the energy efficiency of today's most efficient appliance after two years),
- Establishing a program for promoting the monitoring and visualization of the energy consumption (domestic, services level) in a way that will make visible for the users and more understandable than the readings of meters are (given that these are out of the usual reach of the users),
- Introducing without any delay the education and training on renewable energies, facilitating the fastest way to introduce and expand renewable technologies with assured quality,
- Introduction of financing, legal and fiscal mechanisms and regulations in order to facilitate the previous measures and the technology research.

Besides the general policy measures it is also necessary to initiate **programs and commitments** as the following:

- Establishing a micro-cogeneration programme with ambitious targets,
- Establishing a solar roof programme with ambitious targets,

- Arranging a green community competition on an annual base regarding the local renewable energy generation,
- Arranging a “zero energy buildings” competition on an annual base,
- Establishing a wind energy programme based on small (less than 5 MW) wind farms with ambitious targets,
- Establishing of specific commitments, goals and targets to use public buildings for solar energy production and to start immediately emblematic or “lighthouse” projects in the roofs and façades of the public buildings,
- Directly addressing celebrities / prominent entities to act as a model in utilising solar energy or renewable energies in general
- Promotion of local energy self-sufficiency programs (at the “comarca” level), being based priority on the combined use of renewable energy resources existing in the area,
- Promoting the development of a network of Agencies or Local Energy Centers independent from the administrations and from energy companies, but with their participation and implication, in order to pass the information about renewable energy and energy efficiency to the population
- Creation of equitable partnerships between rural zones and urban zones, given that many rural zones could have a surplus of renewable sources of energy.

Research and development have created renewable and efficient energy technologies for a permanent energy supply. Together the political community and industry must take measures to implement a "solar strategy". The measures described above are feasible and make sense. The most important step is to start now, since every day that goes by without enforcing a solar strategy only increases and complicates the problem – because energy consumption is increasing, money is still being invested in fossil fuel systems and finding ways to solve the problem of climate change is merely being postponed.

In order to democratize and establish a decentralized or distributed energy system in ways that are efficient, safe, clean and renewable, it is important to recognise a set of **basic energy rights**:

- the right to know the origin of the energy one uses,
- the right to know the ecological and social effects of the manner in which energy is supplied to each final user of energy services,

- the right to capture the energy sources that manifest themselves in the place where one lives,
- the right to generate one's own energy,
- the right of fair access to power networks and grids,
- the right to introduce into power networks energy generated *in-situ*,
- the right to a fair remuneration for the energy introduced into networks,

These rights have to be matched by set of **basic responsibilities**:

- the responsibility to find out information,
- the responsibility to ask for information,
- the responsibility of generating energy with the most efficient and clean generation technologies available,
- the responsibility to use the most efficient end-use technologies available,
- the responsibility of conservation: of using the generated energy with common sense and avoiding any kind of waste,
- the responsibility of self-limiting oneself in the use of any form of energy,
- the responsibility of solidarity with those societies underprivileged in access to clean means of energy generation as well as final use.

Guaranteeing these rights it should be one of the tasks in which the governments should give the most absolute priority. Exercising these responsibilities it should be considered like the fundamental duty of the responsible persons who live in a planet where the Sun is the source of energy that we depend on. Adapting the lifestyles to the solar energy flows (both direct solar energy and their indirect forms) it being fast discovered that when the transition is being carried out, swiftly, less costs of every kind will have to be borne for humans to be able to sustain life and prosperity on Planet Earth.

Outlook to future work

The recent work does not cover all aspects that have to be investigated in order to plan and establish an optimised system of renewable energy supply for Catalonia. Although it could be demonstrated that renewables potentials are sufficient to supply 100% of Catalonia's electricity demand by renewable technologies, a more in-deep analysis and a more sophisticated and detailed simulation will surely uncover substantial optimisation potentials to get a leaner energy supply system and to further reduce system costs.

As this study provides a solid base for planning the direction Catalonia's energy supply should take, it should be used as a starting point to set up a framework with ambitious long-term and intermediate goals for renewable capacities, supporting measures / schemes and benchmarking of measures and working plan to address further research and development needs that are necessary to develop a detailed roadmap towards SolarCatalonia.