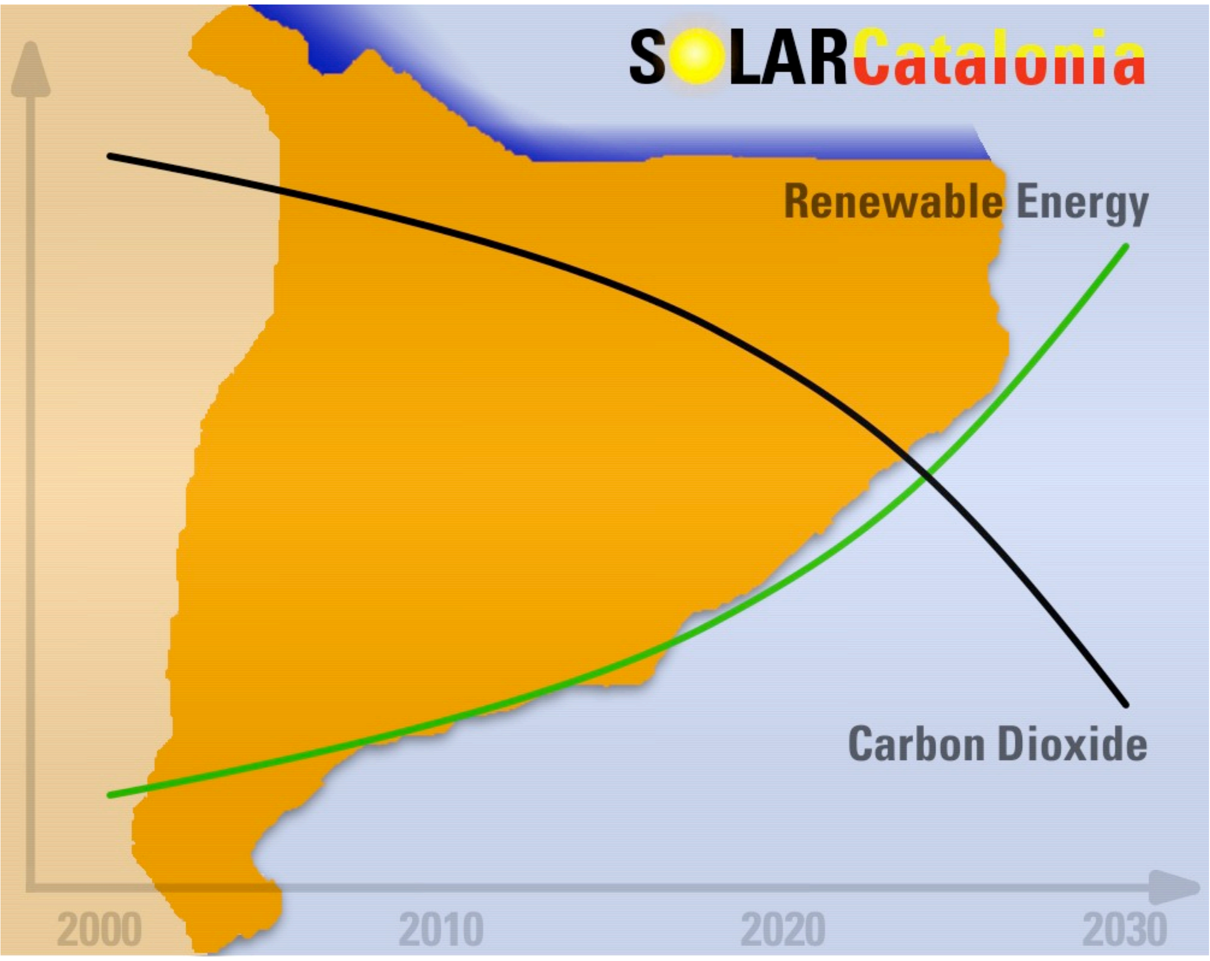
Solar Catalonia II

A Pathway to a 100% Renewable Energy System for Catalonia

A simulation of Catalan electric system based on the analysis of the hourly meteorological data and electricity load's profiles for 2007



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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]. Some voices even demand that industrialized countries have to reduce their GHG emissions by 100% until 2050[6]. 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[7]. The German commitment stipulates to reduce greenhouse gas emission by 40% until 2020.

The serious consequences of using fossil fuels, the risks of nuclear energy and the still unresolved problem of nuclear waste 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.

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[1] Stern 2006, Summary of conclusion, S. vi

[2] IPCC 2001

[3] Quoted from the IPCC's Fourth Assessment Report, Working Group III.

[4] developed nations produce 80% of the world total greenhouse gas emissions from fossil fuels.

[5] Cf. UBA 2005a, p. 15

[6] Mac Glade

[7] Percental GHG reductions in relation to 1900 levels

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 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 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[8]. Other studies, e.g. "Long Term Integration of Renewables into the European Energy System"[9] and "Sustainable Energy Supply Against the Background of Globalisation and Liberalisation"[10] 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 one of the front-runners 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 need for electricity. This entails that the study does not consider

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

[9] "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

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

any major changes in lifestyle and that the reductions in energy demand do not cause negative changes in living standard. This does not impose that the authors do not expect a change in lifestyles within the next decades. The availability of resources, not only but especially fossil energy resources, will force a shift towards a more sustainable lifestyle with less resource consumption. If societies will judge this change as a reduction in lifestyle depends on how we shape this transition and on the way we will change our definition wealth and modern life.

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 system with the SimREN simulation software[11] and policy measures to deliver best support for a sustainable energy supply.

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[11] 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 Catalonia is able to supply its own need for electricity from renewable sources and that this is more a question of advancement than one of retrogression. 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.

Although Catalonia showed a strong economic growth within the past, 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 2043 and to about the half of 2007'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, most of the way solely consist of revoking the increase in energy intensity we saw in the past. The remaining effort in efficiency improvements is not of an extend that should make us doubt that this goal can be achieved. In fact the efficiency target used in this work is almost in line with the EU efficiency target, which aims at increasing energy efficiency by 1.5% per year[12]. Translated to energy intensity the EU target results in decreasing energy intensity to 54% of the 2009 level until 2050.

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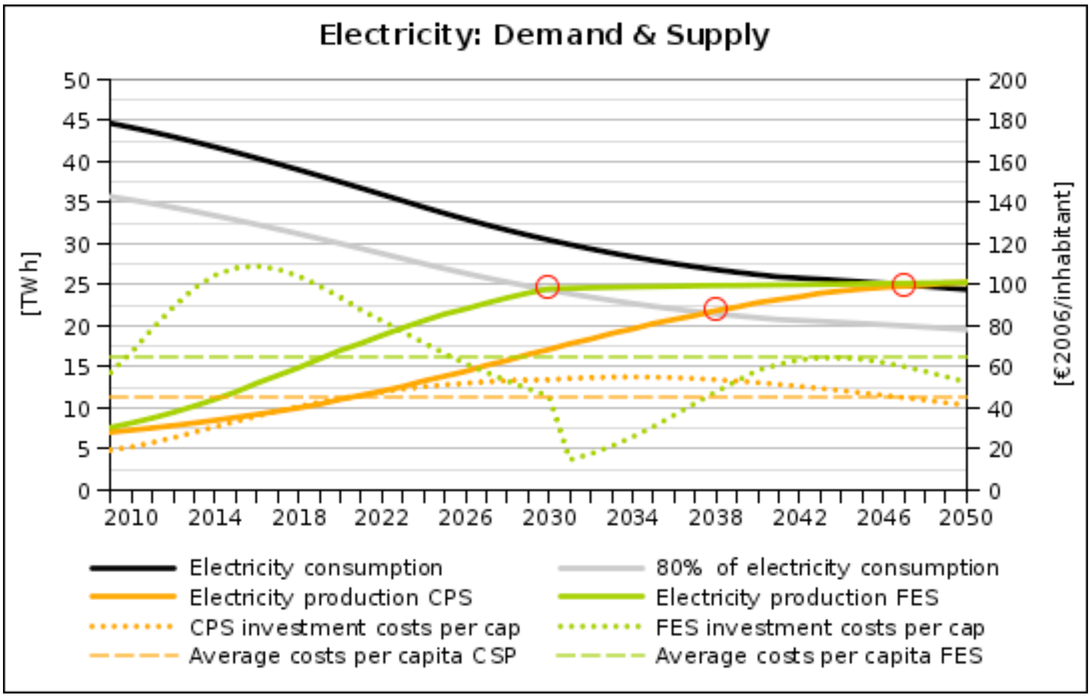
[12] Source: Action Plan for Energy Efficiency: Realising the Potential [COM(2006) 545]; 2006

Both scenarios show the feasibility to achieve a fully renewable supply until 2050. 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 109 €$_{2006}$ per inhabitant in the "Fast Exit Scenario" and 55€$_{2006}$ / 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 (see Picture 1). It must be stated her that these costs are pure investment cost for renewable generating capacities. Neither there are other costs included (e.g. operation costs), nor are there cost savings in other parts of energy supply system considered, such as fuel savings and the related cost reduction or savings in the external costs of energy supply.



Picture 1: Development of electricity demand and supply in the scenarios. Source: SolCat II; 2009.

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 45 €$_{2006}$ per inhabitant and year in the "Climate Protection Scenario" and 65 €$_{2006}$ per inhabitant and year in the "Fast Exit Scenario".

Compared to the Catalonian Gross Domestic Product (186,324 million € in 2008, on 2006 price base) the annual costs of the scenarios are 0.19 % of the GDP for the "Climate Protection Scenario" and 0.27 % for the "Fast Exit Scenario" on average. In contrast to the resulting costs, the development - as described in the scenarios - will create jobs[13] and will lower the export of capital by reducing costs for imported fossil fuels.

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[14].

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 or more for exporting electricity) 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

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[13] The German example show this job creating effect impressively.

[14] Electric mobility was also not considered although electric cars can be used as a storage in electricity supply.

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 optimizing the electrical energy system in general but, e.g. for wind energy, best locations were chosen among those that are suitable for installation. This simulation was done continuously for one year with typical weather of the year 2006[15]. Demand management is also included in the energy supply model. As there was no detailed simulation of single consumers, the basic assumption is that demand side management will be able to cut peak loads in electricity demand by 10% without changing the absolute amount of energy consumed in a year (load shifting).

Taking the results of the simulation according to the “Fast Exit” scenario, the system is capable of supplying all the electricity demand in Catalonia. While solar power shows it's best performance from late spring to autumn, Wind energy performs best during late winter and early spring, remains on medium level until late summer but drops considerably then. Late autumn again shows days with higher wind energy performance on occasion.

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 the total electricity demand or even more.

The distinct seasonal variations of the fluctuating part of the supply system force the adjustable part of electricity supply to show a contrary behaviour: Hydropower, Geothermal & Biomass and Imports[16] (from other regions in Spain or France) have to contribute more during autumn and winter.

From autumn to late winter the adjustable suppliers have to contribute most to electricity supply, as the decrease in solar irradiation appears in conjunction with generally lower wind speeds. Looking at the big picture the climate variation over the year, with strong wind performance especially in late winter/early spring, good solar and medium 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 utilization of hydropower coincides with higher precipitation levels, geothermal- and biomass plants can mainly be operated

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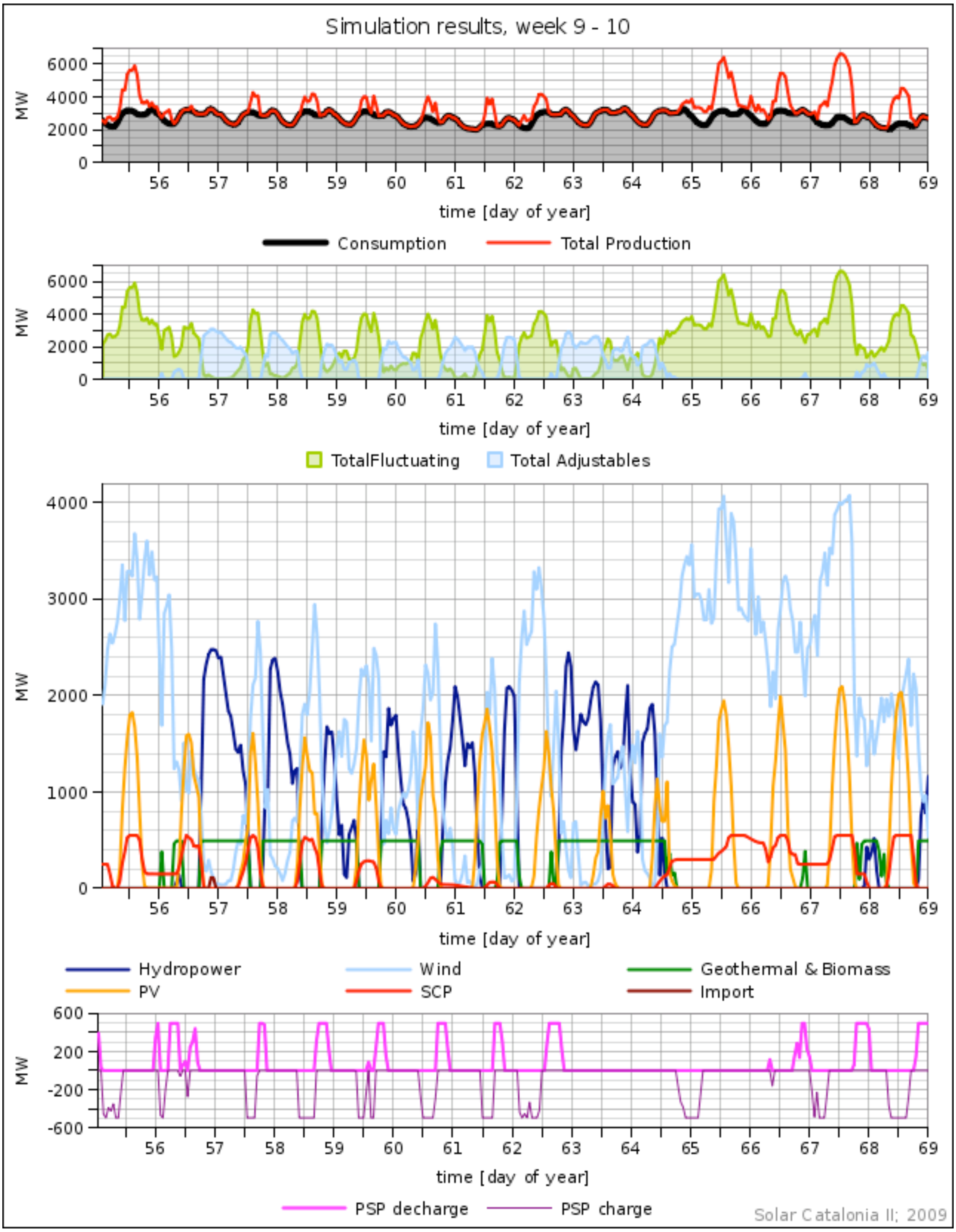
[15] Source: [MeteoCat; 2006]: *Servei Meteorològic de Catalunya (*Dades EMA integrades a XEMEC). Department de Medi Ambient i Habitatge

[16] The simulation considers the possibility to import electricity from neighbouring regions and/or countries. To reduce imports it would also be possible to further increase the generating capacities in Catalonia itself.

during times with a higher demand for heat, thus giving the opportunity to take advantage of high efficient combined heat and power plants.

Basically an electricity supply system with a high share of fluctuating suppliers benefits from a strong interconnection with neighbouring regions and countries. It is likely that surpluses from fluctuating sources, and deficits due to the breakdown of fluctuating supply too, will not occur simultaneously in all regions of wide and strong connected area. Therefore strong connections for electricity transport will be a key issue for compensation of fluctuations as they enable the export of surpluses to such regions with an actual deficit. Nevertheless each single region should be optimized with regard to fluctuations in it's own electricity supply.



Picture 2: Results of the simulation for the weeks nine and ten. Source: SolCat II; 2009.

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 all of the projections it is assumed that the pace of efficiency increases is 2.5% per annum, which can be maintained until 2025. In the aftermath the projections given here expect successively decreasing efficiency gains and – lastly- no further reduction after about 2040.

Projections for the further development of the Gross Domestic Product has been performed by least square curve fitting to the historical data. All GDP projections are on a 2008 price base, with two differing assumptions regarding annual inflation rates. While one extrapolation is meant to provide a reference for better comparison (extrapolation at price stability, which is an inflation rate of 2% per annum according to the European Central Bank), the other one considers an annual inflation rate of 3.4% per annum, which is the average inflation in Spain from 1995 to 2008. The later one is used for electricity demand projections.

History of Energy Consumption in Catalonia

Primary Energy Consumption

The Primary Energy Consumption increased by about 43% from 1993 to 2007, which is an average annual growth of 2.8% (see picture below). The absolute Primary Energy Consumption raised from about 18,222 ktoe in 1993 to about 26,840 ktoe in 2007[17].

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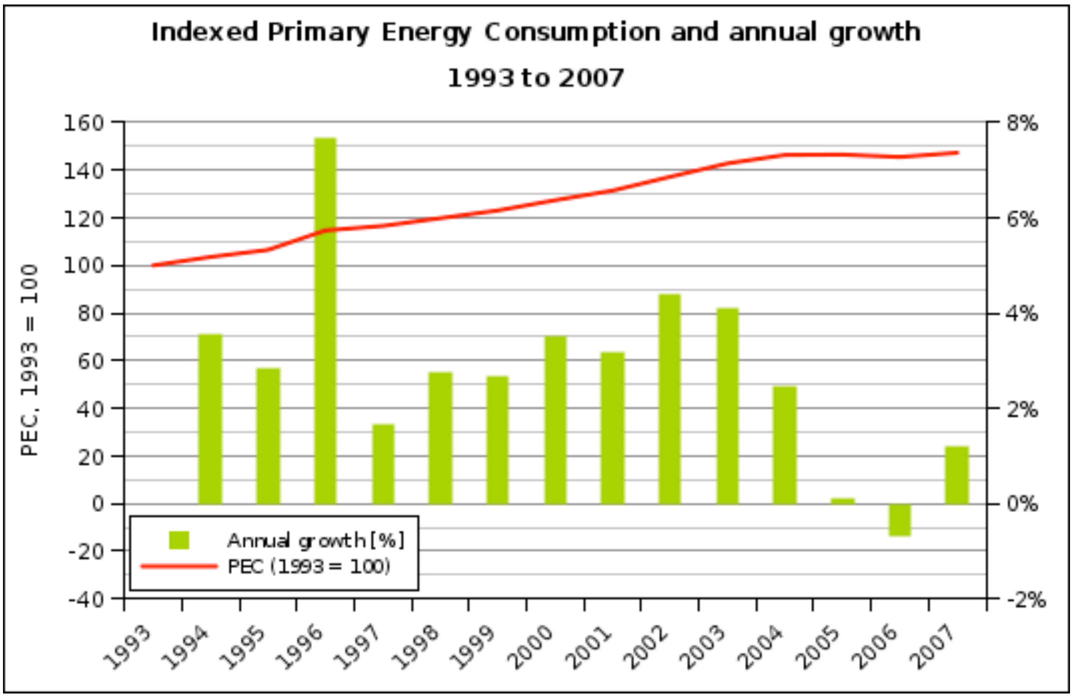
[17] Sources: IDESCAT, ICAEN; http://www.idescat.cat/pub/

The data shows that there was virtually no further increase (3% from 2003 to 2007) in primary energy consumption after 2003, which marked the end of the dataset used in the first edition of the "Solar Catalonia" study.



Picture 3: Index of Primary Energy Consumption 1993 to 2007, 1993 = 100. Own calculation. Datasource(s): IDESCAT, ICAEN.

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 149 tons of oil equivalent per million € of GDP[18] in 1993, which increased to about 153 toe/million € GDP in 2003. Since then a decrease in primary energy consumption per gross domestic product can be observed: in 2007 PEC per GDP has fallen to slightly more than 90% of the value in 1993 (approximately 137 toe/million € GDP in 2007)[19].

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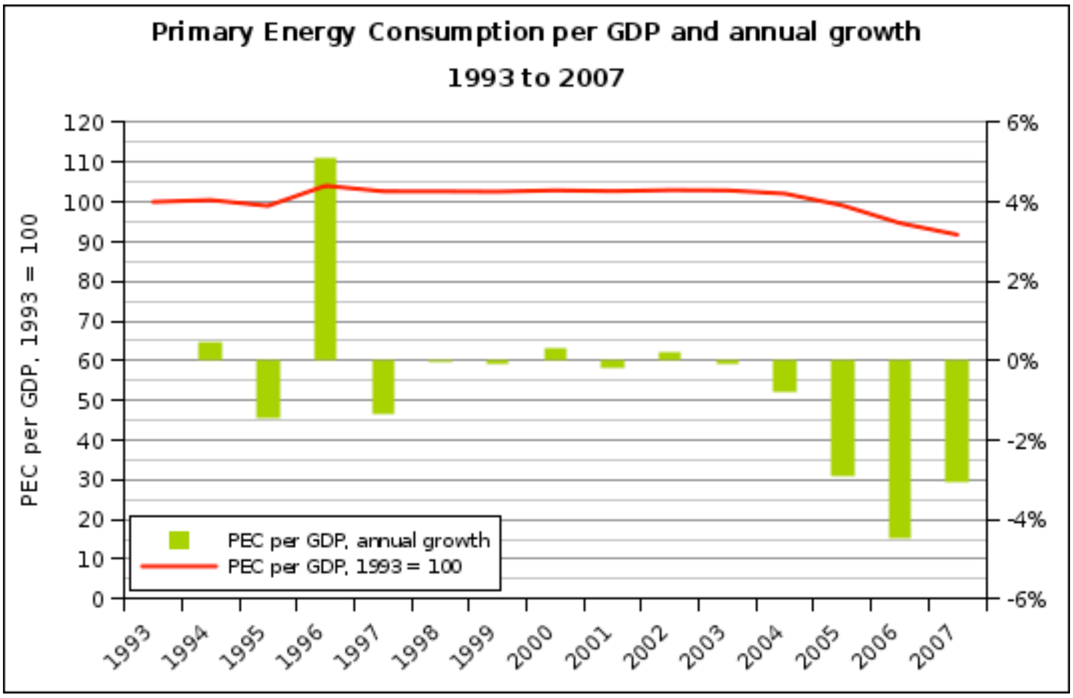
[18] Inflation-adjusted GDP series with price base as of 2008.

[19] Source: own calculation based on IDESCAT, ICAEN.



Picture 4: Development of the Catalonian Primary Energy Consumption per GDP and annual growth rates, 1993 to 2007, 1993=100. Own calculation. Datasource(s): IDESCAT, ICAEN.

Electricity Consumption

Electricity consumption in Catalonia showed a steady growth from 1993 to 2007. With an average annual growth rate of about 4% per year, electricity consumption increased by almost 80% in total, from about 26,500 GWh in 1993 to about 47,300 GWh in 2007 (see picture below). After 2003 annual growth rates of electricity consumption decreased, so the growth of electricity consumption slowed down during that period. In 2004, 2006 and 2006 annual growth rates have been lower than in any year from 1993 to 2003[20].

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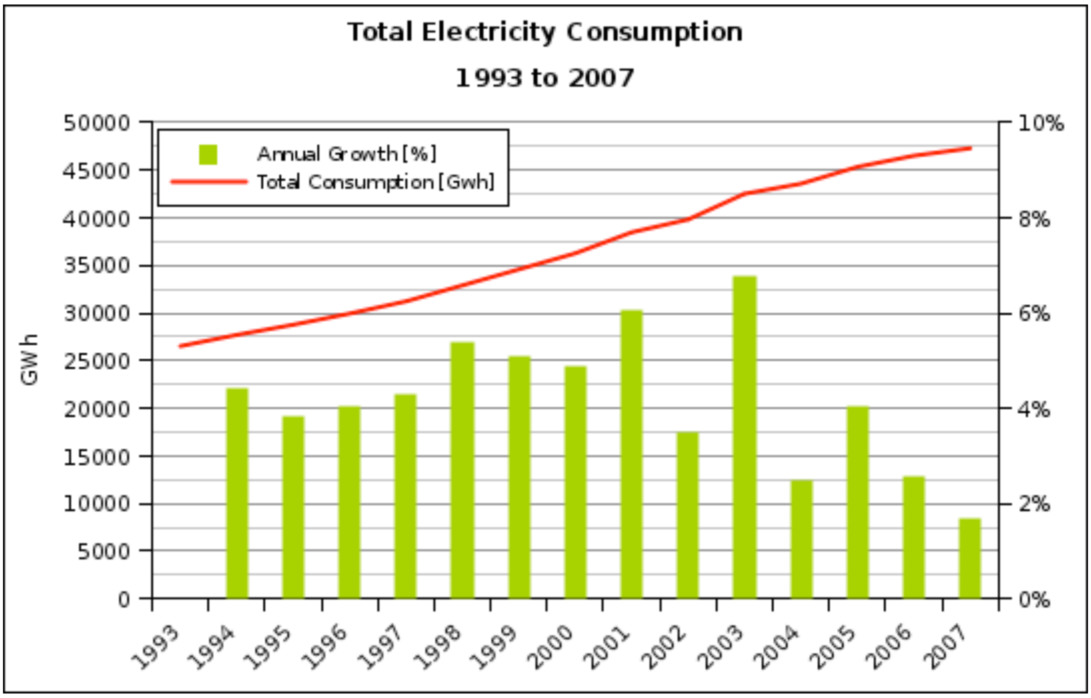
[20] Sources: IDESCAT, ICAEN.



Picture 5: Development of gross electricity generation and available electricity production in Catalonia, from 1993 to 2007. Sources: IDESCAT, ICAEN.

Since the growth in electricity consumption outperformed growth of the GDP[21], there was a massive increase in the electricity consumption per Gross Domestic Product, at least until 2003 (Picture 6). From 1993 to 2003 electricity consumption per GDP raised from 217 kWh per thousand € to about 250 kWh / thousand €. This is an increase of more than 15% in total or 1.5 % on annual average. Afterwards the situation changed. In 2006 and 2007 there was a substantial decrease in electricity consumption per GDP (more than 1% to almost 3% in both years), which brought consumption down again to about 241 kWh per thousand Euros of GDP. This is en par with the specific consumption in 2000.

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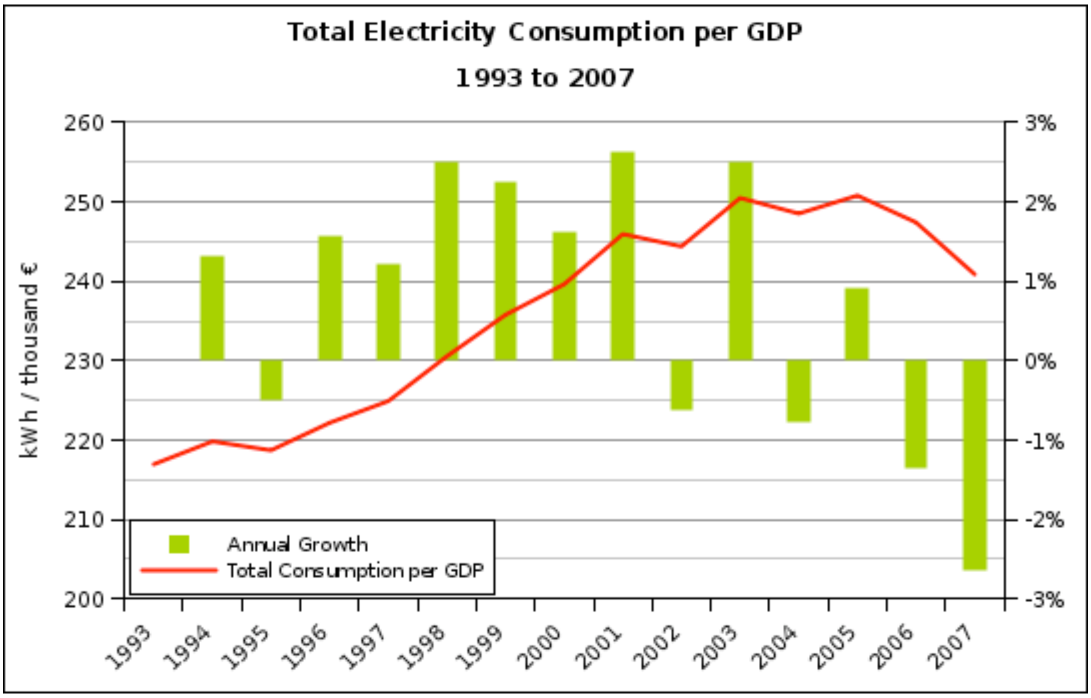
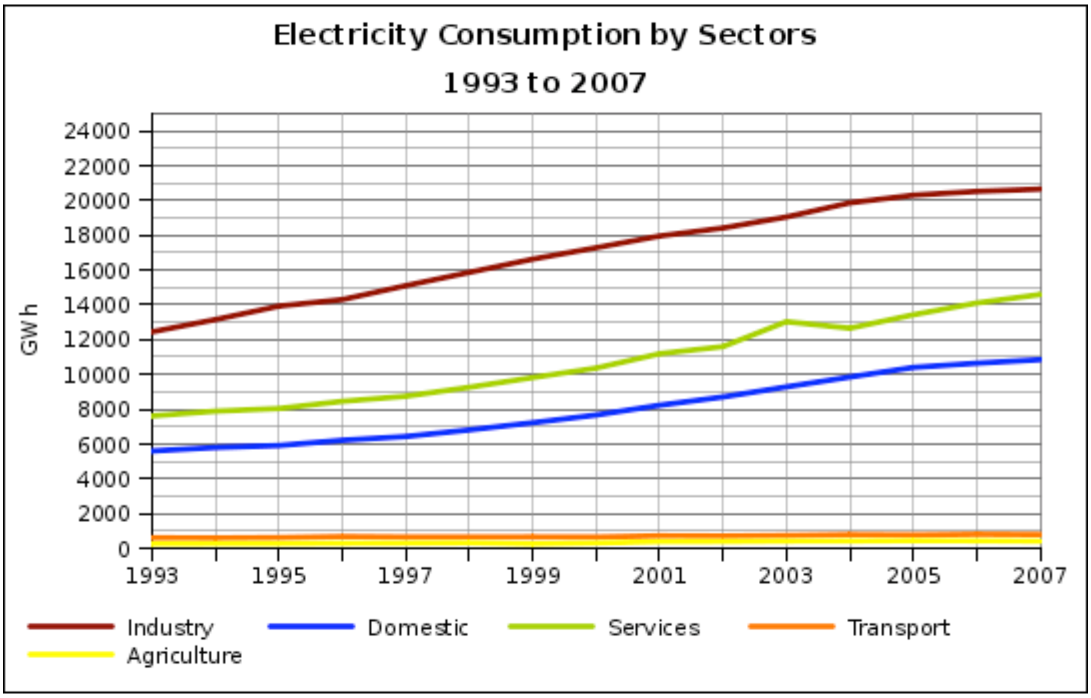
[21] Inflation-adjusted GDP series with price base as of 2008.



Picture 6: Development of the total electricity consumption and annual growth rates, 1993 to 2007. Sources: IDESCAT, ICAEN.

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).

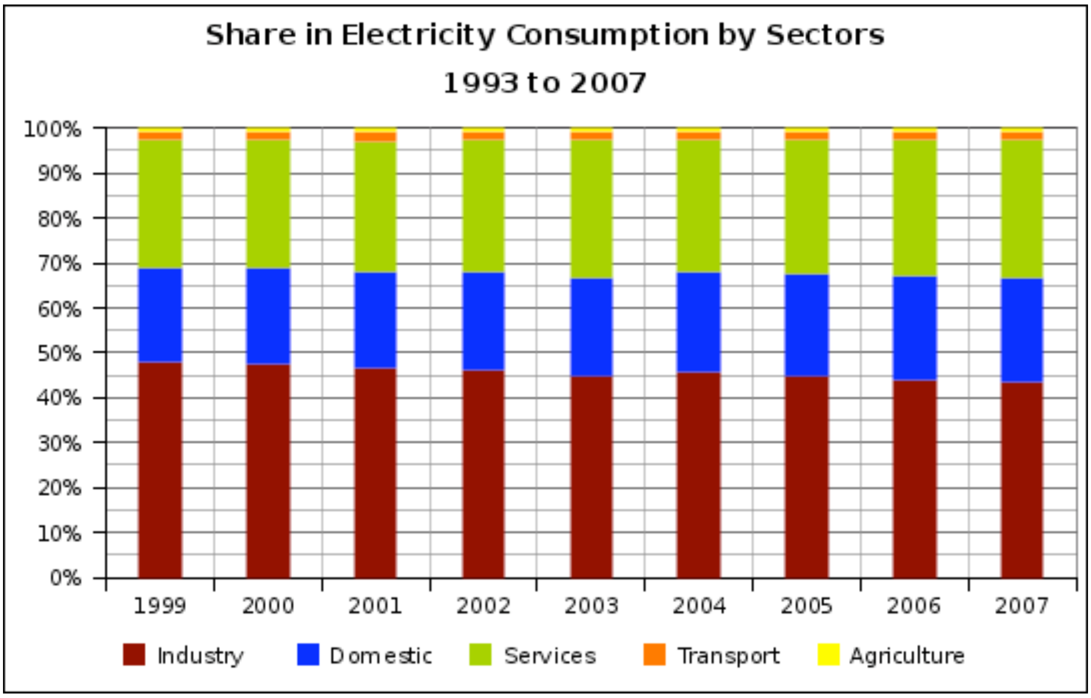


Picture 7: Development of Electricity Consumption by Sector, 1993 to 2007. Sources: IDESCAT, ICAEN.

Data about the distribution of electricity consumption among the different sectors is available since 1999, before statistics gave one value for the agricultutral, domestic and services sectors together.

From 1999 to 2007 the industrial sector lost some share in electricity consumption (down from 48% to about 44%), while the services and the domestic sector increased their shares; from about 28% to almost 31% for services and from almost 21% to about 23% for the domestic sector.

Altogether there was not much change in the structure of electricity consumption: the industrial sector still is the biggest consumer of electricity in Catalonia in 2007, followed by the services sector and the domestic sector. The shares of the agricultural and transport sectors are only marginal.



Picture 8: Development of electricity consumption's structure by sector demand, 1993 to 2007. Sources: IDESCAT, ICAEN.

The sectoral comparison of energy intensity (electricity consumption per GDP from 1993[22] to 2007, Picture 9) results in the industrial sector (red line) having the biggest increase in energy intensity (plus 36%), whereas the services sector (green line) and the domestic sector (blue line) both show an increase by 11%.

In total the industrial sector showed a steady and considerable increase in electricity intensity latest until 2005 (accelerating after 2000) but then shows a decrease from 2006 to 2007; like never before since 1993. The two remaining sectors, domestic and services, did not show that much increase if compared to the industrial sector. While increase in the services sector seems to slow down after 2001, the domestic sector keeps the upward trend until 2005 but shows a decrease in energy intensity afterwards.

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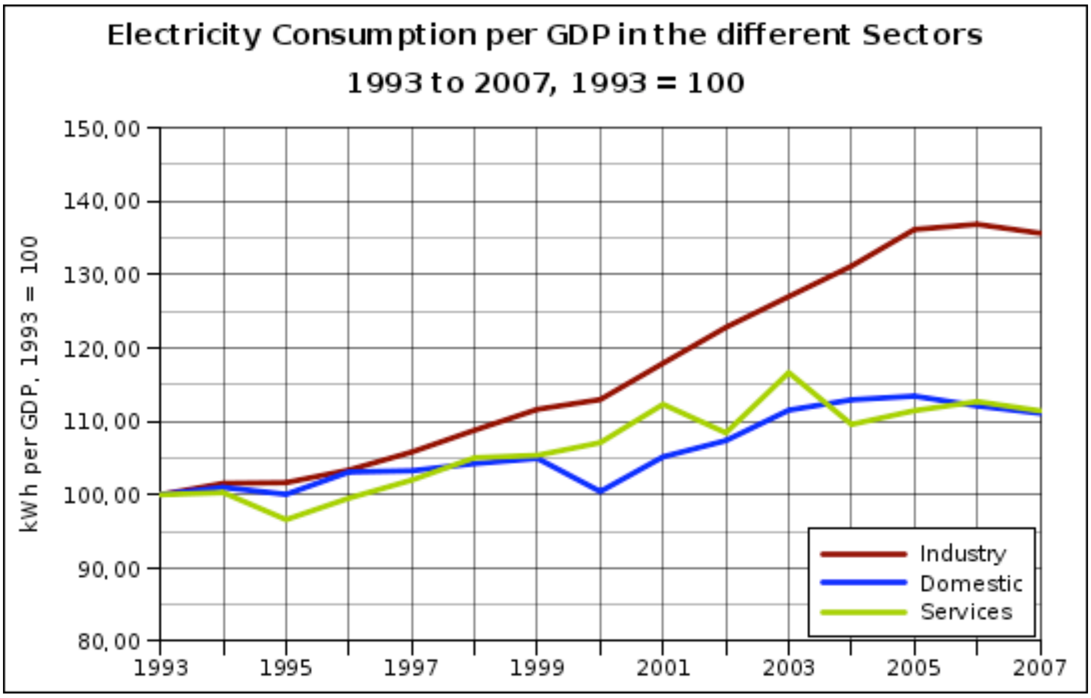
[22] Sectoral values for the time before 1999 have been disaggregated using the average distribution between domestic, primary and services, as no detailed values for the different sectors were available.

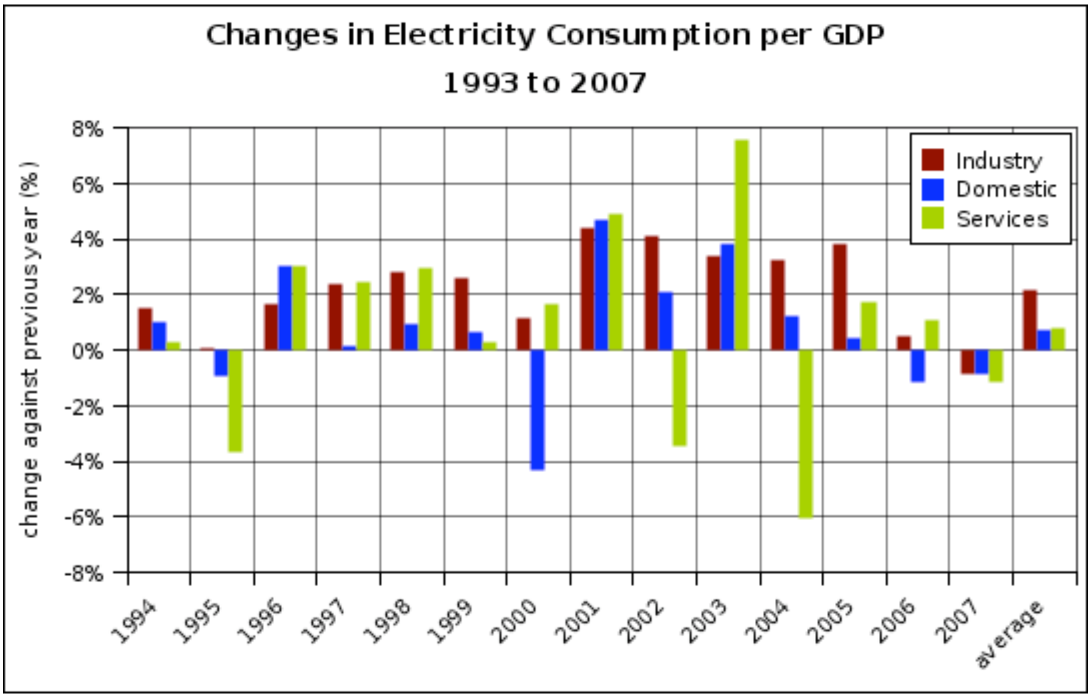


Picture 9: Electricity consumption per GDP in the different sectors, 1993 to 2007; 1993 = 100. Own calculation based on IDESCAT, ICAEN.

The annual rates of change (Table 1and Picture 10, below) reflect the increase in energy intensity in the years after 2000 for the industrial and the domestic sector. Considering the long term annual average (1993 to 2007) for the three sectors, the industrial sector achieved an annual average increase of 2.2%, followed by the services and the domestic sector with annual increase in energy intensity of 0.8% in average.

Sector	**average annual increase in energy intensity**		
	1993 to 2000	**2000 to 2007**	**1993 to 2007**
Industry	1.9%	2.5%	2.2%
Domestic	0.2%	1.3%	0.8%
Services	1.1%	0.4%	0.8%

Table 1: Rates of change in energy intensity for the industrial, services and domestic sectors, 1993 to 2007. Sources: IDESCAT, ICAEN.

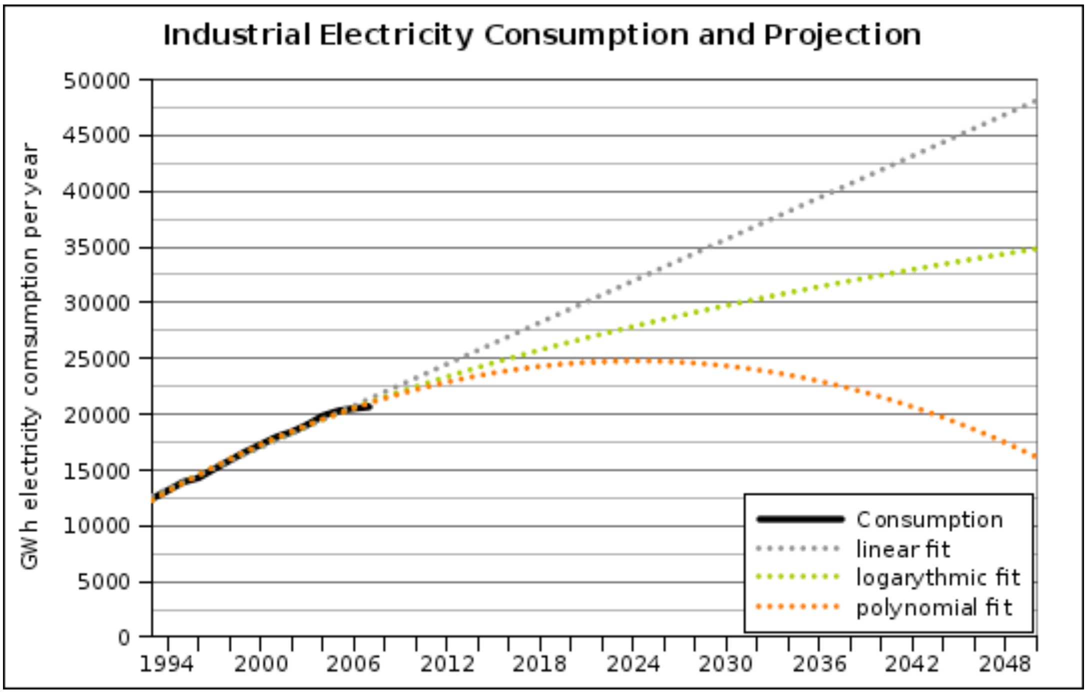


Picture 10: Rates of change in energy intensity for the industrial, services and domestic sectors, 1993 to 2007, interpolated values before 1999. Sources: IDESCAT, ICAEN.

Projection of Energy Demand in Catalonia

Industrial Sector

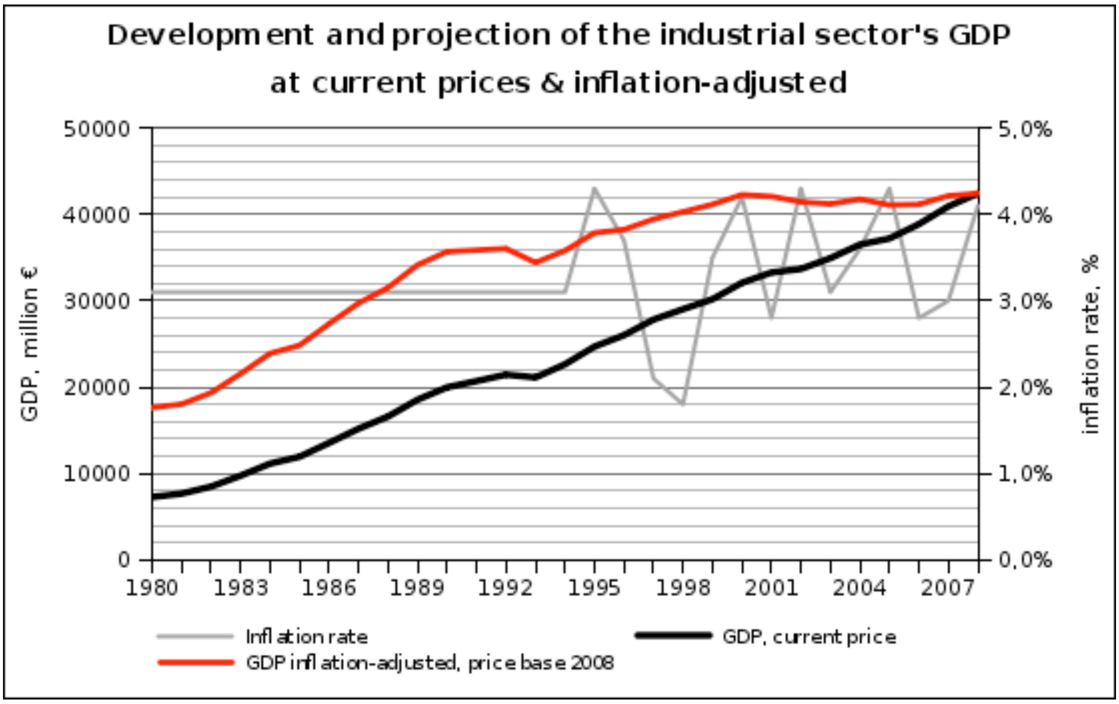
From 1993 to 2007 the industrial sector showed an increase in electricity consumption from 12,450 GWh/a to 20,650 Gwh/a (black line in Picture 11), which is an annual increase by 3.7%. Projecting the historical development into future has been done by linear (grey dotted line), logarithmic(green dotted line) and polynomial regression (orange dotted line), where the logarithmic regression showed the best fit to historical data (Picture 11). According to this projection the industrial electricity demand will grow by about one third, to almost 30,000 GWh, until 2030 and further to about 35,000 GWh in 2050.



Picture 11: Development of electricity consumption in the industrial sector. Source: SolCat II; 2009, data source: Institut Catala d'Energia, Balanc electric 1990 – 2007; 2009.

To calculate energy intensity in the industrial sector the gross domestic product in this sector must be considered too. The published data gives the gross domestic product (GDP) at current prices, which is the value of the GDP at money's purchasing power of the corresponding year. In this way – and knowing that there is inflation, GDP increases from year to year even if there was no increase in production, but only an increase in prices.

To get a better impression of the purchasing power this GDP development represents Picture 12 contains the development of GDP at current prices (black line), the inflation adjusted development of the GDP (1993 price base, red line) and the related annual inflation rates (grey line)[23]. The comparison shows that if inflation is considered too, the GDP of 1980 represent a much higher value at today's purchasing power; i.e. industrial production of 1980 is revaluated by the price level of today.



Picture 12: Development and projection of the industrial sector's gross domestic product at current prices and inflation-adjusted. Own calculation based on data from IDESCAT.

If energy intensity in any sector gets measured by the GDP at current prices, without any consideration of inflation, this would automatically result in a chimaera of increasing energy efficiency, even without technological advances. In the following energy intensity therefore gets measured by the inflation-adjusted GDP with a price bas as of 2008. The future inflation rate is assumed to be 2%, which is the so called price-stability criterion of the European Central Bank.

The projection of GDP's development into future shows the best curve fit for the logarithmic regression (Picture 13, green dotted line), which shows a further growth of GDP (at current prices) to about 104 billion € in 2050; an increase by 145% if compared to 2008[24]. Considering a future inflation rate of to2% (price stability) shows that the effective value of the GDP (red line) will not show much further increase. By 2050 the inflation-adjusted value of the GDP will be about the same level as in 2008. If future inflation rate is assumed as the

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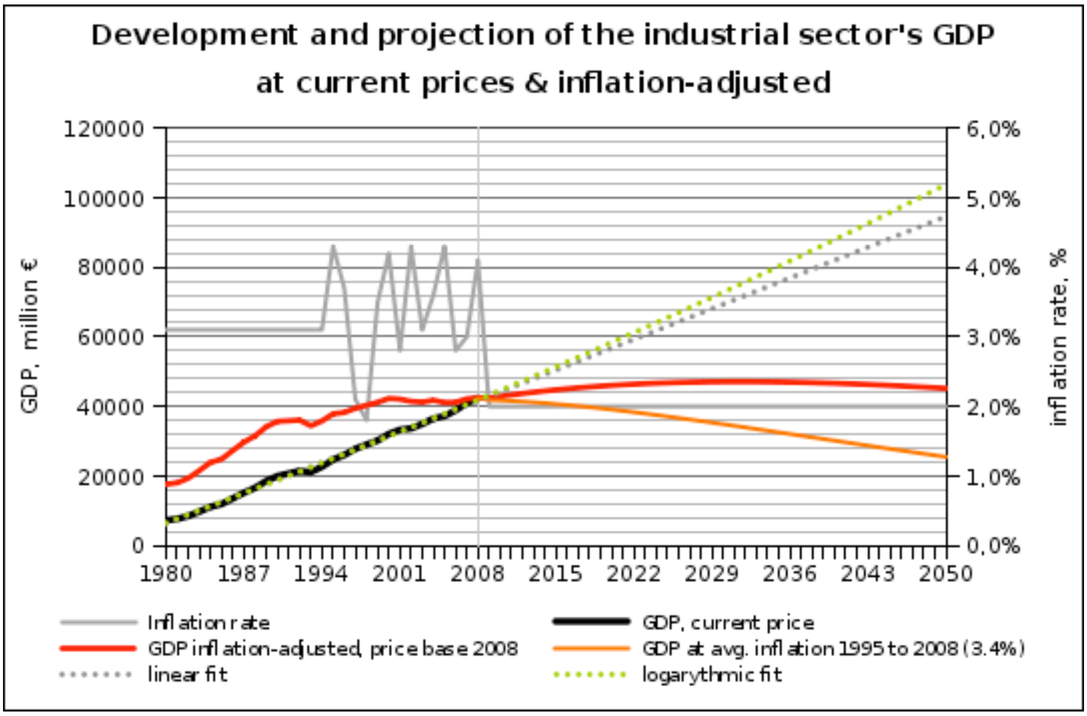
[23] Inflation rates from 1980 to 1994: 3.1% (average from 1995 to 1999); 1995 to 2008: historical data [IDESCAT]; 2009 to 2030: 3.4% (average from 1995 to 2008).

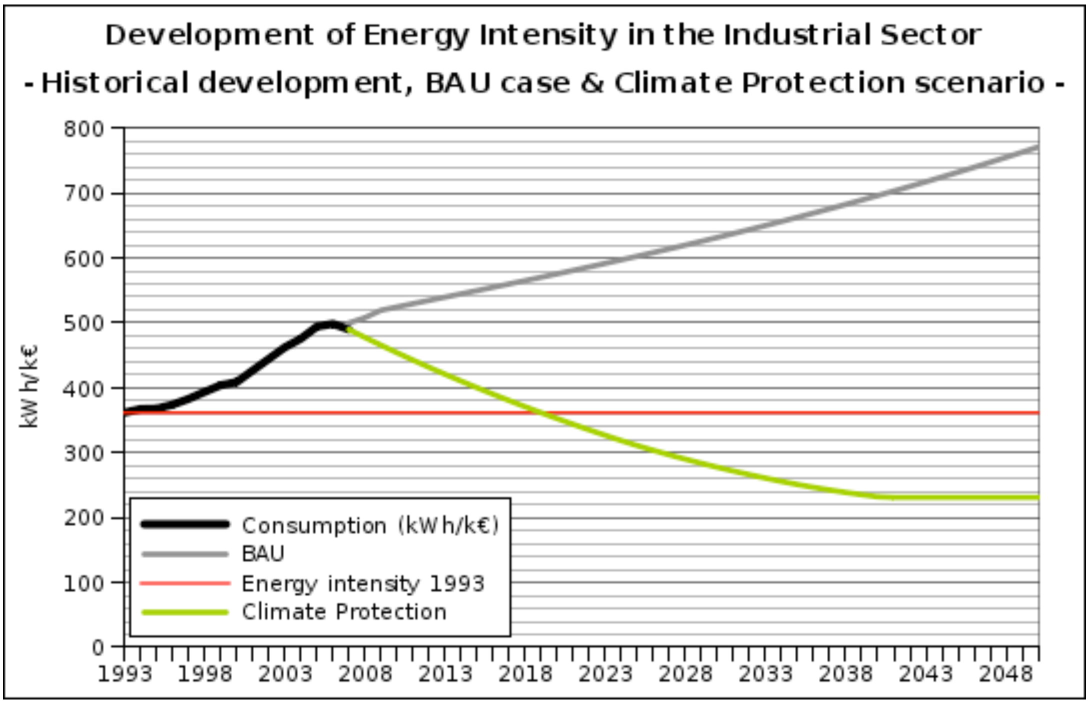
[24] Linear projection (grey dotted line in Picture 13) shows a similar development.

average inflation from 1995 to 2008 (3.4%, grey line) there will be considerable decrease of the inflation-adjusted GDP until 2050.



Picture 13: Development and projection of the industrial sector's gross domestic product at current prices and inflation-adjusted. Own calculation based on data from IDESCAT.

From 1993 to 2007 there was an increase in energy intensity of about 2.2% per year in 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 14). According to this scenario electricity consumption per GDP will grow by a factor of 1.6, from 490 kWh/k€ in 2007 to 771 kWh/k€ in 2050.



Picture 14: Development of energy intensity in the industrial sector, BAU case and “Climate Protection” scenario. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

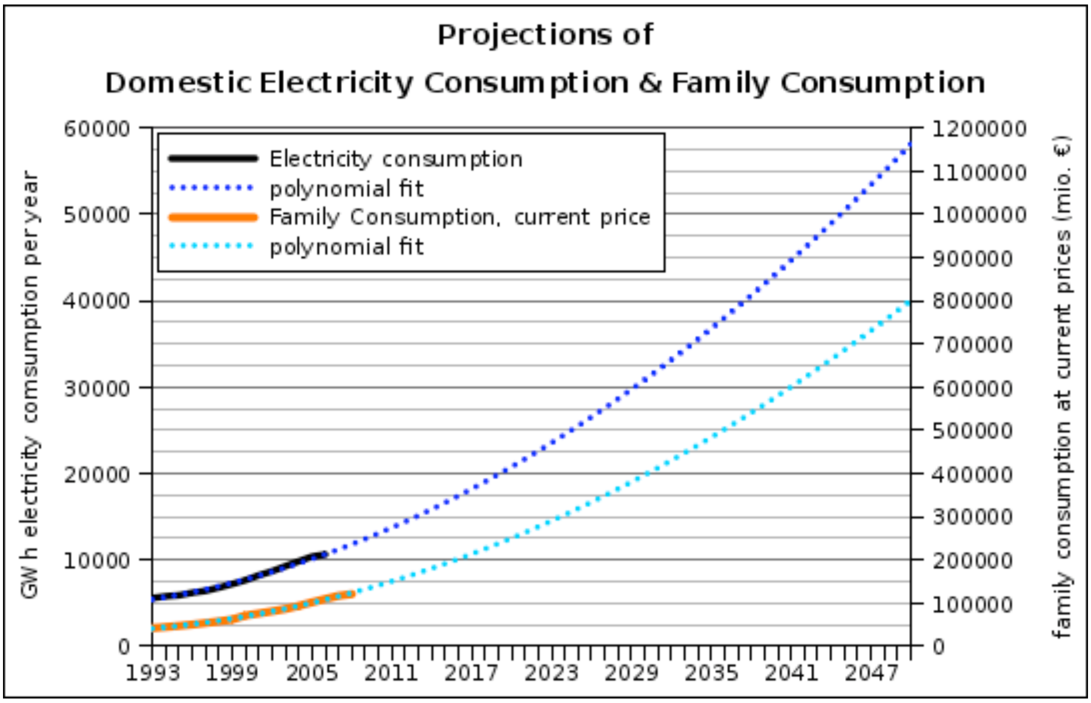
The “Climate Protection” scenario (green line) assumes strong efforts in increasing electricity efficiency. It is assumed that efficiency improvements of 2.5 % per year until 2025. Afterwards the scenario assumption is that further increases in energy efficiency will be harder to achieve from year to year, as the value approaches to the scenario’s threshold of 50% of the 2003 figure, which is the same goal as in the previous “Solar Catalonia” study. Consequently there is a successive slow down in reduction rates, with no more reductions after 2040, the time when half of 2003's energy intensity is reached.

Altogether the energy intensity reached in the “Climate Protection” scenario by 2050 is about 70% 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 1,1% per annum, which is in strong contrast to the further increase in energy intensity in the BAU case.

In terms of absolute values the electricity intensity of the industrial sector in the “Climate Protection” scenario decreases from 490 kWh per thousand Euros (kWh/ k€) in 2007 to 231 kWh/k€ in 2050. A reduction to 1993’s level will be achieved until 2019.

Domestic Sector

As well the electricity consumption in absolute terms (black line in Picture 15) as the development of Family Consumption (FC) at current prices (orange line) show the best curve fit using a 2nd order polynomial regression. The projection of the future development (dotted lines, darker and lighter blue) shows the electricity consumption to outperform the growth of GDP, which will lead to a further decrease in energy efficiency, even in relation the Family Consumption at current prices. Of course development of the Family Consumption here also will dampened by inflation as this was shown for the GDP in the industrial sector (see: Picture 13 on page 22).

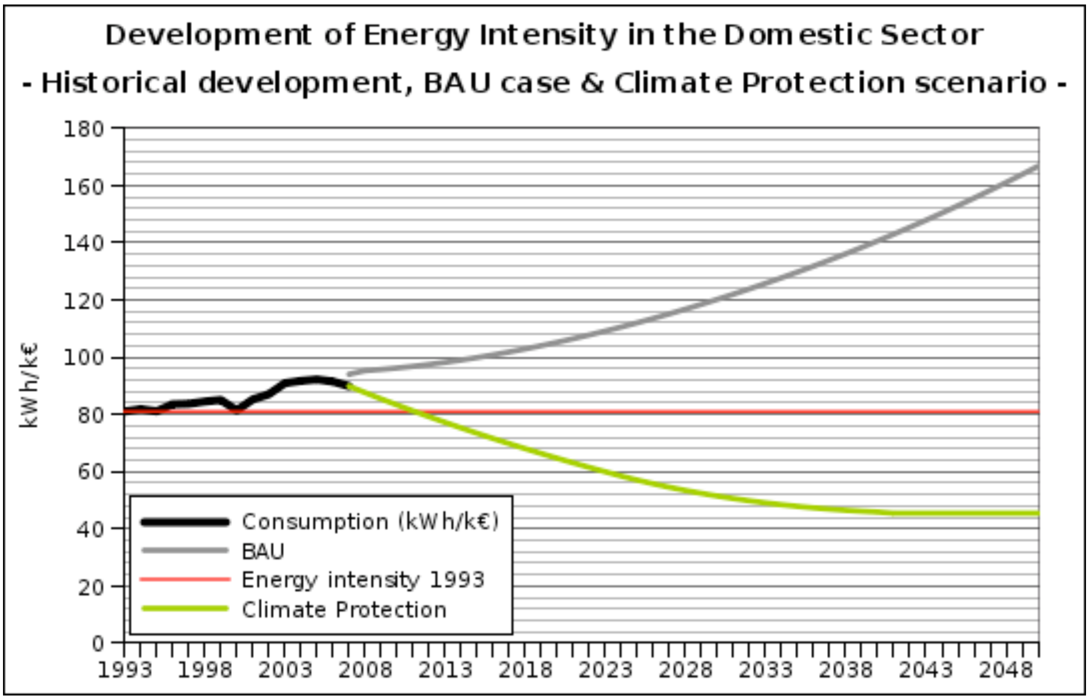


Picture 15: Development and projection of domestic electricity consumption and family consumption. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

The assumption for the „Climate Protection" scenario in the domestic sector (green line, Picture 16) are the same as in the industrial sector, with efficiency improvements of 2.5% per year, a threshold at 50% of 2003's energy intensity by 2050 and a slow down in efficiency improvements from 2025 onwards.

The energy intensity by 2050 is 73% lower in the "Climate Protection" scenario as it is in the "BAU" case, which shows 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 57% of 2007's level. Due to the slow down of efficiency improvements after 2025 the average decrease of energy intensity over the whole period (2007 to 2050) is

1.45%. In absolute terms energy intensity in the “Climate Protection” scenario decreases from 90 kWh per thousand € of family consumption in 2007 to about 45 kWh/k€ in 2050. The 1993 level of energy intensity will again be reached during 2011[25].



Picture 16: Development of energy intensity in the domestic sector, BAU case and “Climate Protection” scenario. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

Services Sector

As in the other sectors, the trend development indicates a further massive growth in electricity consumption as well as in the sector's GDP (see Picture 17). Regression analysis shows the best curve fit using a 2nd order polynomial regression (dotted lines) for both, electricity consumption (black line) and the sector's GDP (orange line). Measuring energy intensity by the GDP's development at current prices would result in a considerable decrease of energy intensity. This picture changes if inflation, even at the level of price-stability, is considered too (see BAU case in Picture 18).

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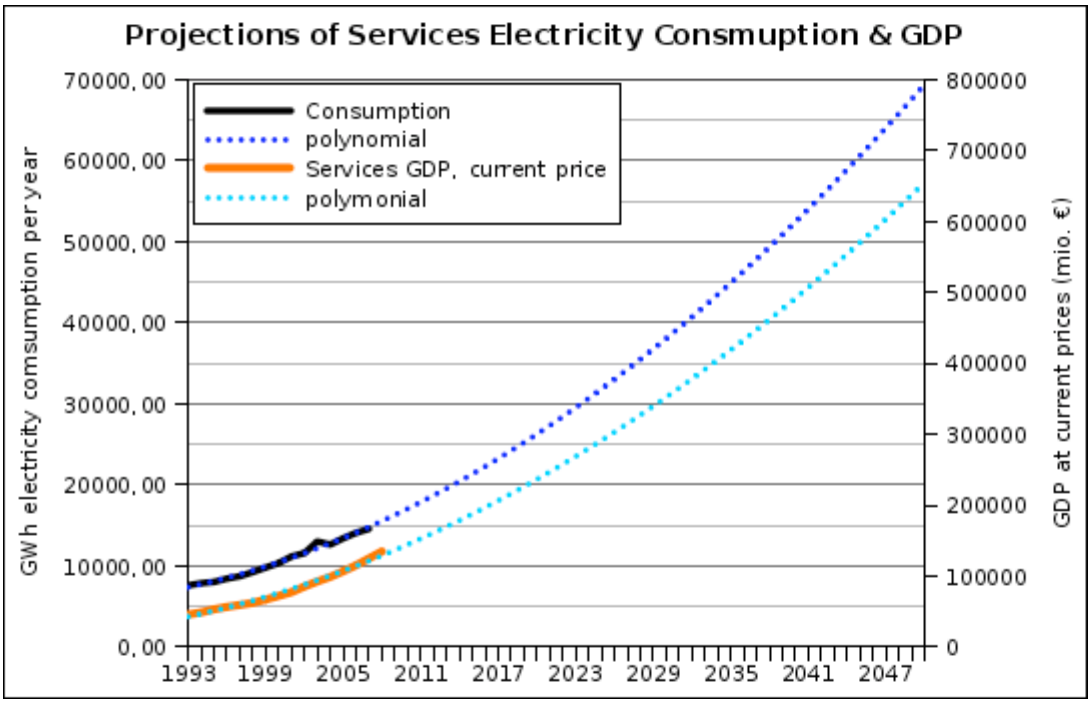
[25] Translated into electricity consumption per person this is 1,064 kWh per person and year, assuming that in 2050 the Catalonian population will be 8.4 millions. In 2007 electricity consumption per person and year was 1,500 kWh in Catalonia.

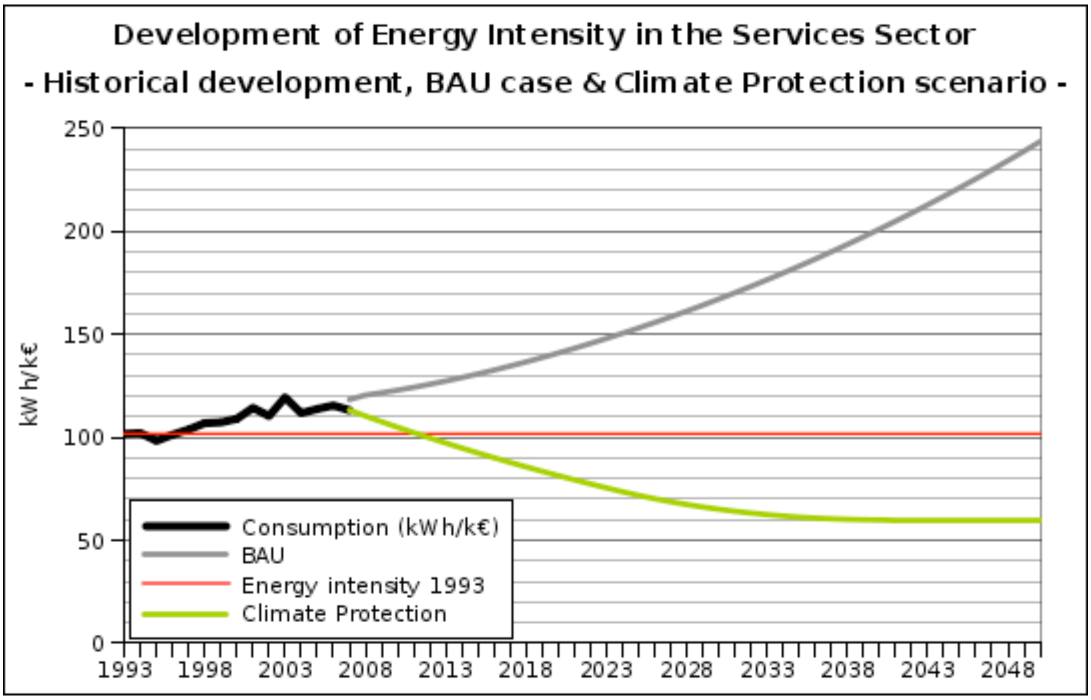


Picture 17: Development and projection of domestic electricity consumption and family consumption. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

In line with the assumption for the other sectors, the "Climate Protection" scenario assumes the annual average reduction in energy intensity from 2003 to 2050 as 1.4%; with 2.5% efficiency improvement from 2007 to 2025 and a slow down in the aftermath. In the "Climate Protection" scenario energy intensity drops to about 58% of 2007's level until 2030 and further to about 53% of 2007' level by 2050; this also represent the chosen target to reach half of the energy intensity of 2003.

Comparing the BAU case and the Climate Protection scenario shows that, by 2050, energy intensity in the Climate Protection scenario is about 75% lower than in the BAU case.

Considering the absolute energy intensity, this figure will drop from 113 kWh/k€ in 2007 to 60 kWh/k€ in 2050. The 1990's level of energy intensity will again be reached during 2011.

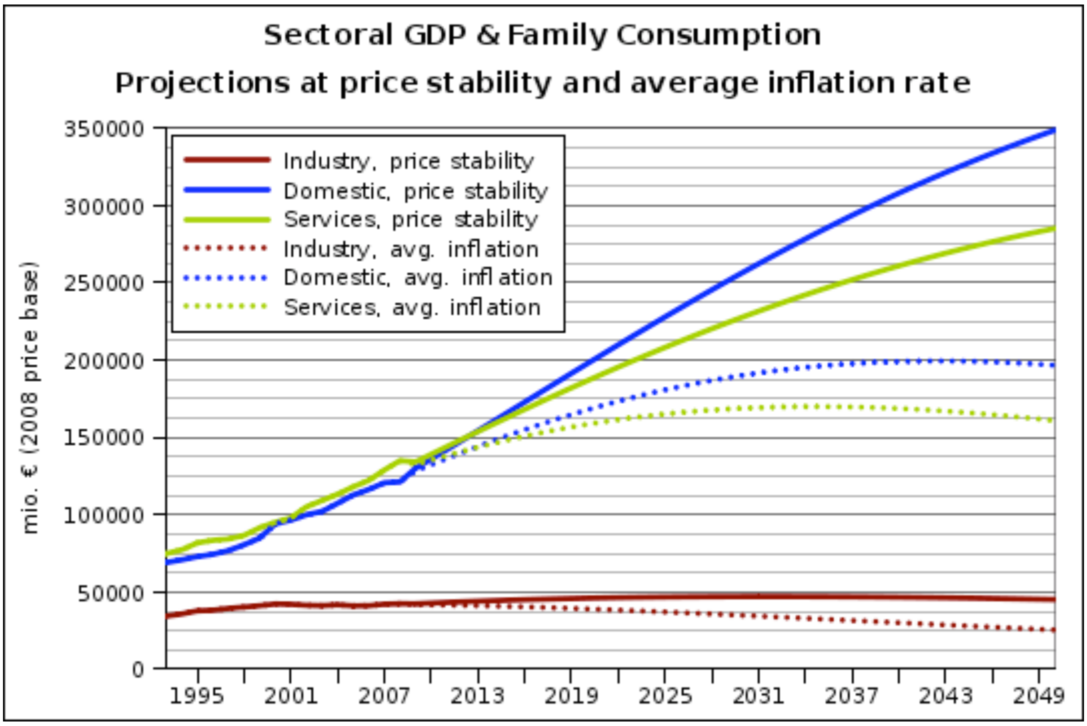


Picture 18: Development of energy intensity in the service sector, historical data, BAU case and “Climate Protection” scenario. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

Projection of the absolute electricity consumption

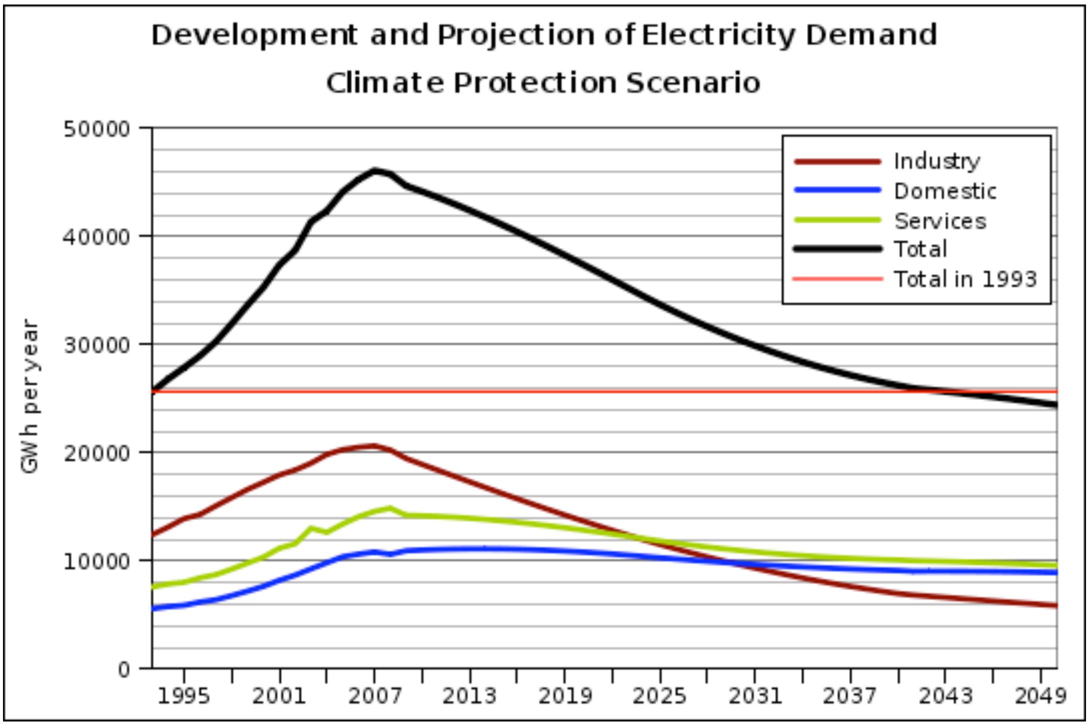
The further development of the single sectors GDP and family consumption is represented by the projection the corresponding regression analysis resulted in. Future inflation is included in two variants: an average inflation from 1995 to 2008 (the scope of the available data) of 3.4% per annum is used for the projection of future electricity consumption and price stability (2% inflation per annum, according to ECB), which is included for comparison (see Picture 19).

Additionally the consequences of the financial crisis are included according to the OECD's latest Economic Outlook for Spain (OECD; 2009). For this purpose data for the expected GDP's growth and inflation rates for 2009 and 2010 from the OECD's publication are used. An additional assumption is that coming back to normality, i.e.transition to the growth rates of the BAU case, will take two years.



Picture 19: Development and projection of the sectors GDP and Family Consumption. Price stability is an annual inflation rate of 2%, average inflation is 3.4%. Own calculation based on data from IDESCAT.

Under this assumptions the total electricity demand will decrease by about one third until 2030 - to about 66% of 2007's consumption - and then slowly approach to about the half of the 2007 level by 2050. By 2043 electricity consumption will have come down to the level of electricity demand in 1993.



Picture 20: Development of the absolute electricity demand. Source: SolCat II; 2009. Own calculation based on data from IDESCAT, ICAEN.

Considering the projected development in the domestic sector it is quite obvious that the reduction assumption used here are quite conservative. Today every Catalonian inhabitant consumes about 1,500 kWh of electricity per year. Taking the electricity demand in 2050 (according to the projection) this figure would drop to a value of 1,064 kWh per person and year (8.4 million inhabitants in 2050 assumed). The relative high value, resulting from the projection is simple to explain: it is a projection of an inefficient past and present.

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. The most efficient technologies available at the market today allow for most of the necessary reductions, only a minor part will have to be contributed by future technologies. Especially in the domestic sector all the necessary technologies to bring down electricity consumption from 1,500 kWh per person and year to the projected 1,064 kWh per person and year are already available and it is more a problem of personal effort: to behave in a more energy efficient way (awareness) and to change to more efficient equipment. Of course improving efficiency of electricity use means a great effort, whether in personal behaviour and buying decisions or in shifting to energy efficient equipment in the industrial and services sectors, but we are convinced that this is feasible from a technological point of view. Considering the period this work considers, time will help us as most of today's equipment will have to be replaced until 2050, the majority of it likely more than one time. In parallel more and more efficient devices will be available on the market, as the latest development, e.g. the consumer electronics exhibition in Berlin 2009, shows that more an more producers seem to acknowledged energy efficiency as a key feature for the product they want to sell in future. 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 already lost valuable time and making a clear and decisive start now is inevitable to keep transition smooth and to avoid at least the most serious consequences of climate change.

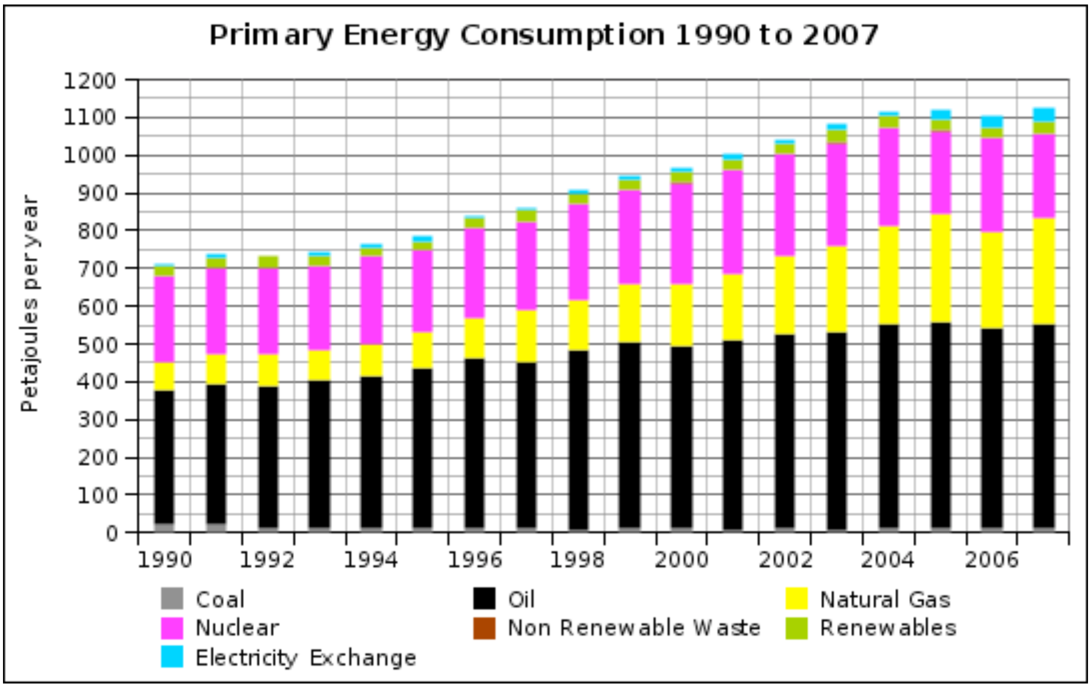
Taking the development as proposed here will bring down Catalonia’s electricity consumption to the 1993 level until 2043 and to about the half (53)% of 2007's electricity consumption by 2050. Even with respect to the facts, that further reductions will be harder to achieve the further we step into future 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, a considerable part of this way solely consist of revoking the increase in energy intensity that could be observed after 1993. 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

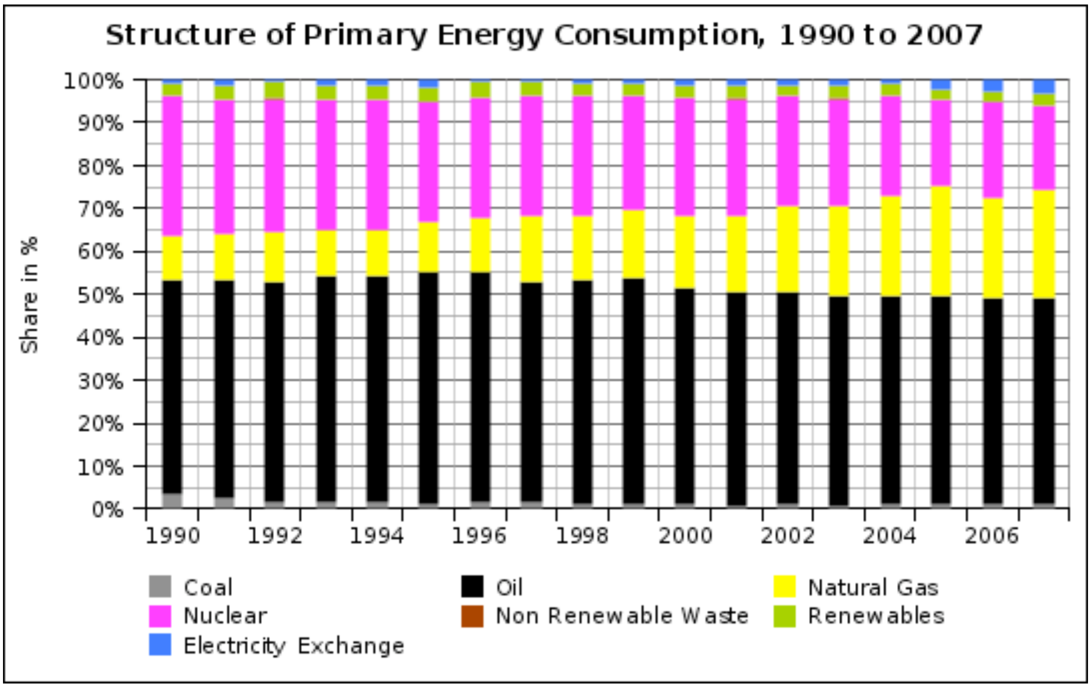
Primary Energy Consumption

Primary Energy Consumption (PEC) increased from about 710 PJ in 1990 to about 1,124 PJ in 2007, a total increase by 58% The increase in Primary energy Consumption shows a considerable slow after 2004. Especially natural gas (plus 207 PJ) and oil (plus 187 PJ) gained importance, while the contributions from coal and nuclear decreased in absolute terms (coal: minus 11 PJ, nuclear: minus 9 PJ). Renewables increased by almost 10 PJ.



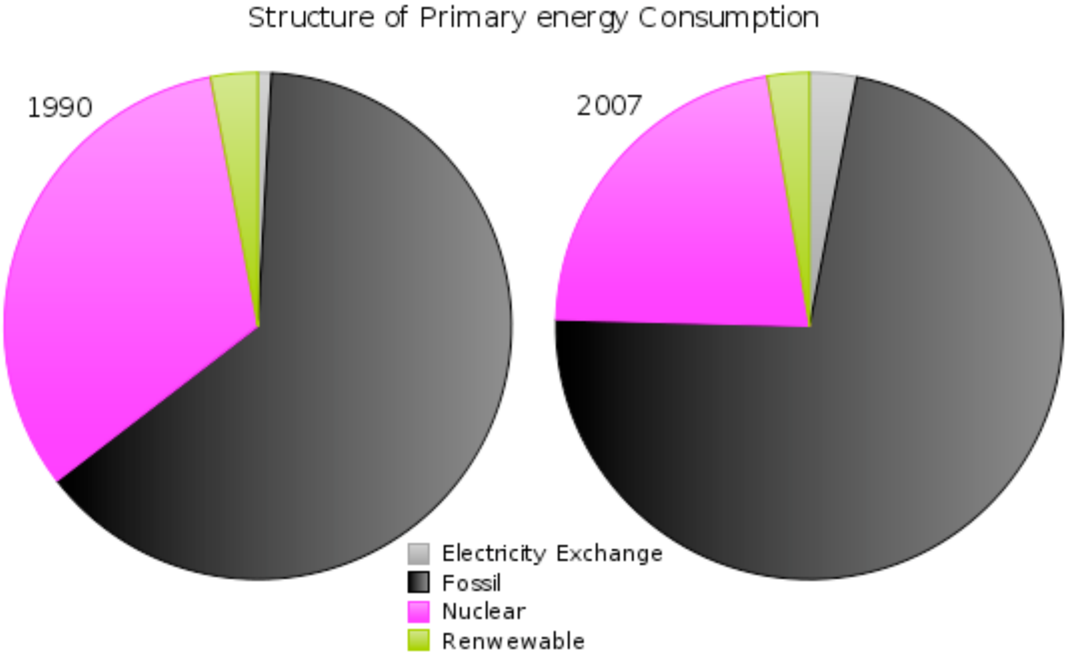
Picture 21: Development of Primary Energy Consumption, 1990 to 2007. Source: Institut Catala d'Energia, Balanç energètic 1990-2007.

The share of Natural Gas at PEC raised from about one tenth in 1990 to one fourth in 2007 and surpassed nuclear energy, which fell from almost one third (1990) to less than one fifth (2007). The proportion oil contributed to PEC increased somewhat during the 1990's but fell afterwards. By 2007 oil made up for slightly lees than the half of PEC; this is about the same share as in 1990. Although showing an increase in absolute terms, the share of Renewables at PEC dropped from 3% in 1990 to less than 2.8% in 2007.



Picture 22: Sources of Primary Energy 1993 to 2003. Source: Institut Catala d'Energia, Balanç energètic 1990-2007.

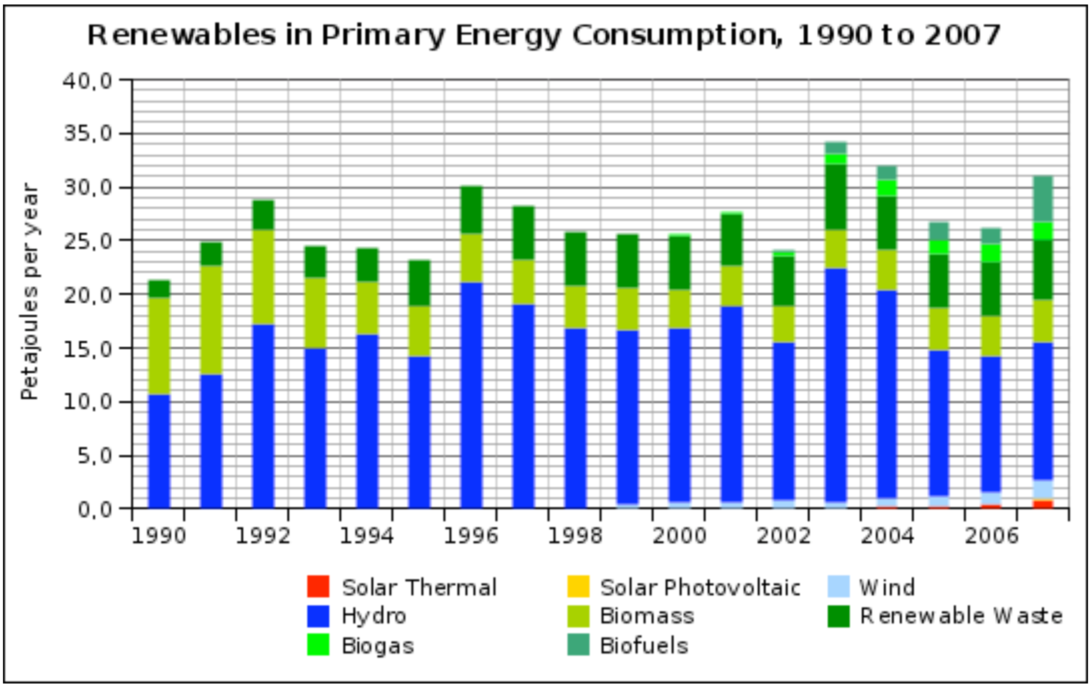
The predominant change in Primary Energy Consumption's structure is the increase of natural gas, which boosted the total share of fossil fuels from less than two thirds in 1990 to about three fourths in 2007. Nuclear energy's share dropped massively. While renewables' share shows virtually no change from 1990 to 2007, there was a visible increase in electricity exchange.



Picture 23: Primary Energy Consumption structure in 1990 and 2007. Source: Institut Catala d'Energia, Balanç energètic 1990-2007.

Renewables in Primary Energy Consumption

As already stated above, the increase of renewables in PEC amounted to an increase of less than 10 PJ from 1990 to 2007. Many of the variations that can be observed in Picture 24 result from annual changes in hydro power production. The contribution of all biomass fractions grew by about 5 PJ, from almost 11 PJ to almost 16 PJ, but there was no steady growth. In 1991 total biomass already showed a value of 12.3 PJ which dropped to about 8.5 PJ until 2002 but then re-increased towards 2007. 2005 shows about the same PEC figure for biomass as already could be observed in 1991. Although there was not much growth, there was a continuous displacement of agricultural & wooden biomass and dung (referred to as “Biomass” in Picture 24) by renewable waste. Since 2000 there are also increasing contribution by biogas and biofuels. Wind energy, already present since 1991, first becomes visible in 2000 and shows a steady further growth until 2007. Solar photovoltaic, present in PEC statistics since 1997, is barely visible in 2007. Heat from solar collectors show a longer history in PEC statistics (already present in 1990) but noticeable growth began by about 2003/2004.



Picture 24: Development of Renewables in Primary Energy Consumption, 1990 to 2007. Source: Institut Catala d'Energia, Balanç energètic 1990-2007.

As renewable PEC in absolute terms basically changed with hydro-power's production from year to year, this is also the case for PEC's structure with regard to renewables (Picture 25), though there are visible and increasing contributions from wind energy (since 1999) and solar collectors (since 2004). Altogether total biomass still contributes half of the renewables PEC in 2007 (as it already did in 1990), while hydro power (41% in 2007) shows a 9% loss in share since 1990[26]. The remaining 9% come from wind energy (almost 6%), solar collectors (almost 3%) photovoltaic systems, with less than half a percent.

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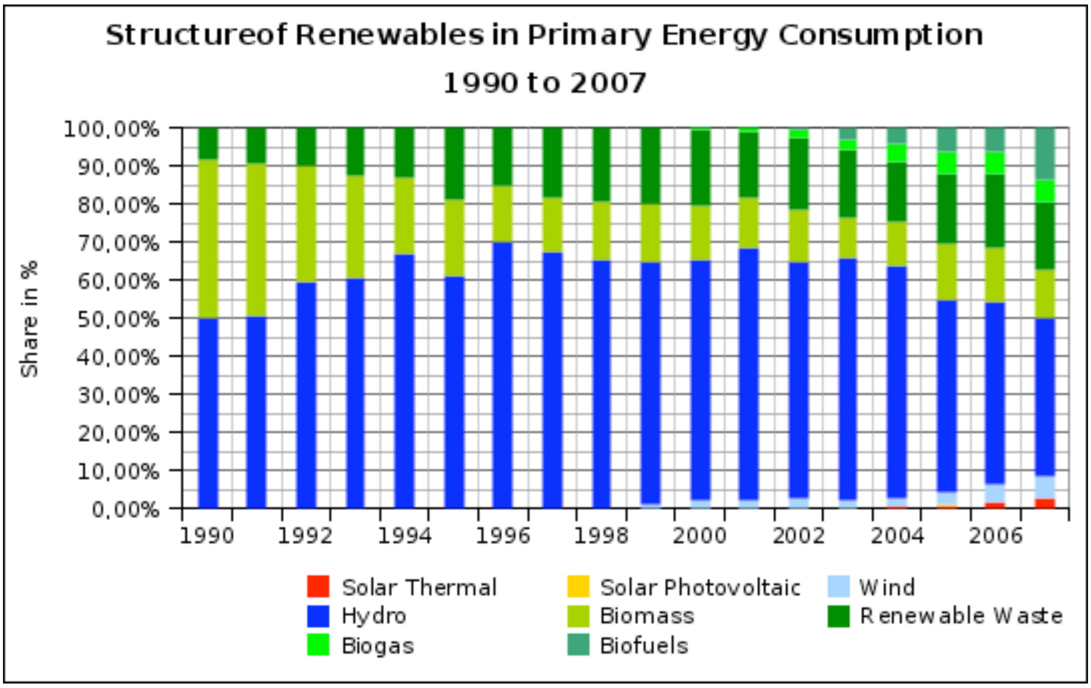
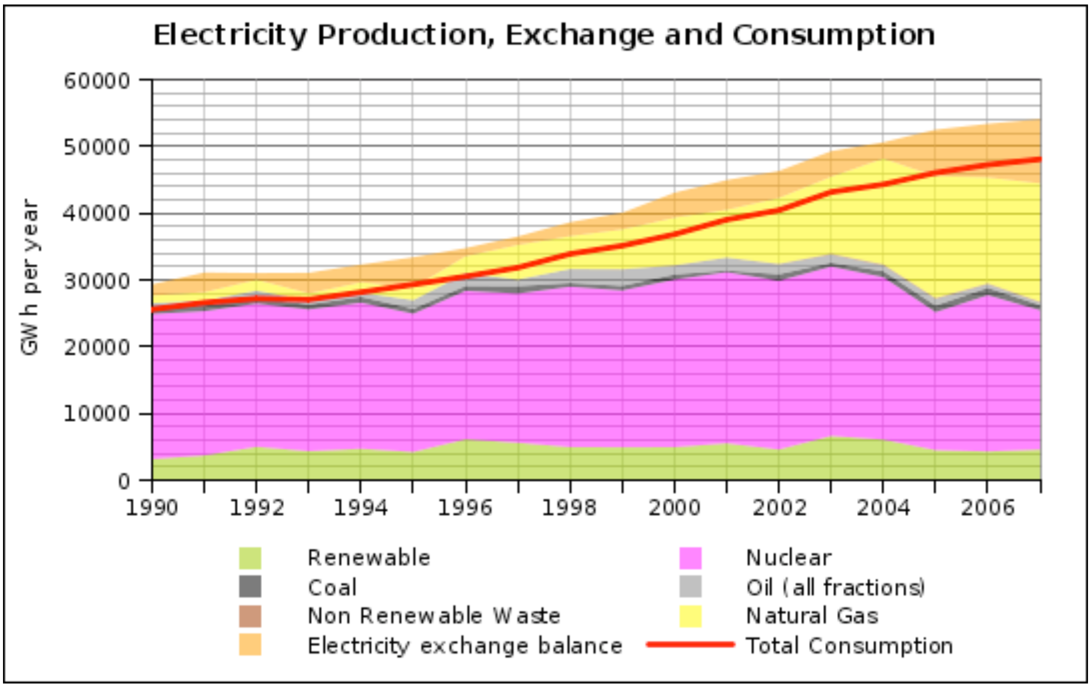
[26] Hydro power performance after 2004 was comparably weak, which is the main reason for the drop in share.



Picture 25: Structure of Renewables in Primary Energy Consumption from 1990 to2007. Source: Institut Catala d'Energia, Balanç energètic 1990-2007.

Final Energy Supply: Electricity generation

With exception to 1993 to 1995 and from 2005 until now, electricity generation in Catalonia showed a steady growth. Gross electricity generation increased from 27,630 GWh in 1990 to about 44,450 GWh in 2007 (see Picture 26). Peak production was in 2004 with 48,160 GWh. Basically the electricity exchange balance shows an import of electricity within a margin of about 1,700 to 4,500 GWh per year. In times when Catalonia's own electricity production dropped, an increase of electricity imports can be observed. Against the variations in own electricity production there was a steady increase in electricity consumption over the whole period, from 25,600 GWh in 1990 to 48,100 GWh in 2007; a growth by a factor of almost 1.9 or by 3.8% on annual average.



Picture 26: Development of electricity supply and consumption in Catalonia, from 1990 to 2007. Source: Institut Catala d'Energia, Balanc electric 1990 – 2007; 2009.

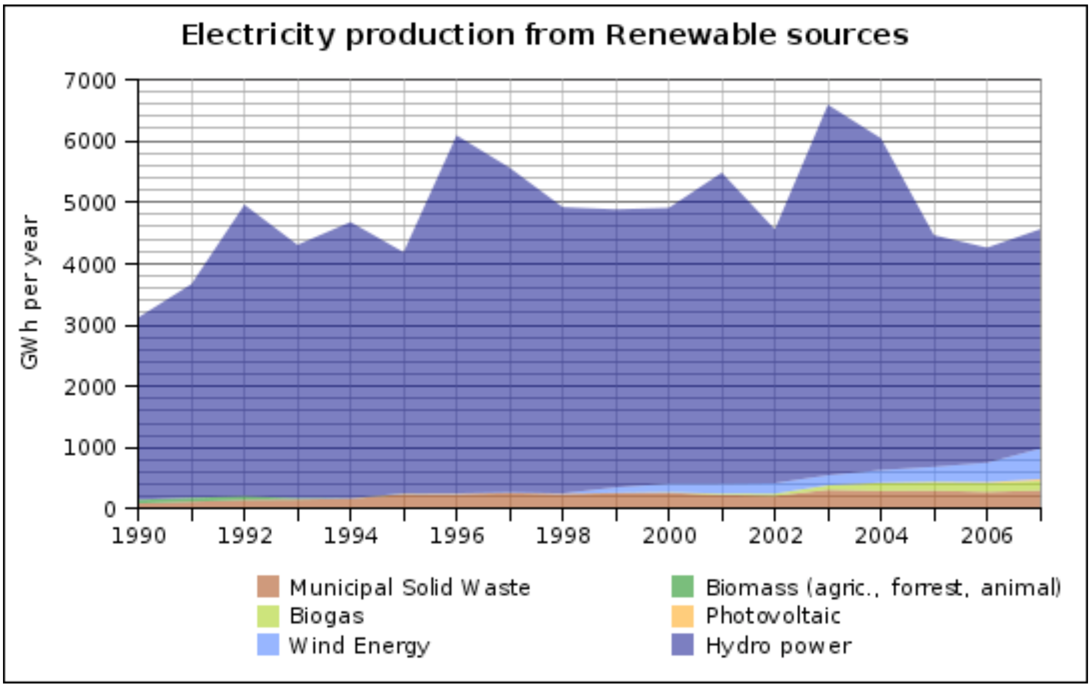
Most of the additional electricity generation was covered by an extended use of fossil fuels (dominated by natural gas) and by import of electricity (Picture 26). While the electricity generation of conventional thermal power plants increased by more than 16,100 GWh from 1990 to 2007, this figure is about -872 GWh for nuclear power; about 20,900 GWh in 2007 with an interims peak of 25,700 GWh in 2001. Although still covering almost 40% of the electricity production in 2007, nuclear power lost a lot of importance: in 1990 about 75% of electricity was produced by nuclear power.

There was not much increase in electricity production from renewable sources; there was an increase of approx. 1,900 GWh for hydro power and 162 GWh for wind energy. Considering total electricity supply this was not enough to avoid a considerable decrease in the share of renewables (down from 10.7% in 1990 to 8.4% in 2007).

Renewables in Electricity Supply

Electricity Production by Renewables

Looking at the renewable electricity generation (Picture 27) it is obvious that hydro power (3,580 GWh in 2007, about 78 % of the total renewable electricity) has by far the lead. Second-best contribution comes from wind energy (about 500 GWh in 2007, approx 11% of the total renewable electricity), followed by solid municipal waste (about 302 GWh, 6.6 %), biogas & solid biomass (154 GWh, 3.4 %) and – with a big gap – photovoltaics (about 30 GWh, less than 1 %).



Picture 27: Renewable electricity generation by sources, 1990 to 2007. Source: Institut Catala d'Energia, Balanc electric 1990 – 2007; 2009.

While there was a steady growth in use of municipal solid waste for electricity production (92 to 302 GWh from 1990 to 2007), the visible growth for wind energy started since 1998 and show a further acceleration in 2007 (7 GWh in 1997 to almost 500 GWH in 2007). While there was some use of solid biomass in the early 1990's (about 60 GWh) this almost vanished towards 2007. Instead there was a growth in using biogas in parallel, which accelerated significantly after 1999 (1 GWh in 1999 to 153 GWh in 2007). Photovoltaic, although merely visible, showed a massive increase during 2007, boosting electricity production from less than 9 GWh in 2006 to almost 30 GWh in 2007.

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[27] up to 127,800 MW[28]. 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 2: 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 [GP; 2005]

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[27] Catalonian Energy Plan, [CEP; 2005]

[28] Renewables 2050, [GP; 2005]

Table 3: Estimated PV potential on residential buildings. Own calculation based on building-data of 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 4), 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	3,61

Table 4: Potential of Solar Thermal Power Plants in Catalonia. Source: [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 5). 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 [GP; 2005].

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 5: Catalonian onshore and offshore wind energy potentials. Source: [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 6).

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 6: Catalonian offshore wind energy potential. Source: Greenpeace, “SeaWind Europe”; 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 7), 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 7 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	0.00	-
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	0.50	6.9%
8 – 8.5	284.7	0.50	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	1.00	13.9%
10.5 – 11	21.7	1.00	13.9%
11 – 11.5	8.3	1.00	13.9%
11.5 – 12	3.1	1.00	13.9%

Table 7: Assumptions for onshore wind energy potential estimation. Sources: SolCat II; 2009, own calculation on base of data from Catalonian Energy Plan.

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 7). 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 8)

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	0.0	0.0	20,675.1
5.5 – 6	977.5	2,443.7	135.8	3,909.9
6 – 6.5	753.7	1,884.1	104.7	3,014.6
6.5 – 7	548.0	1,369.9	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	3.3	8.2	455.0	32,098.0

Table 8: Overview of onshore wind energy potential by wind speed class and area. Sources: SolCat II; 2009, own calculation on base of data from Catalonian Energy Plan.

The total area that gets utilized for onshore wind energy installations is about 455 km^2, which is about 1.4% of the total wind energy potential area as described by the Energy Plan.

The potential given in Table 8 (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 our own calculations on base of 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[29]	**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[30]	**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 9: Additional hydropower potential in Catalonia up to 2015. Source: Catalonian Energy Plan.

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 10, 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

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[29] the Base scenario is a tendentious one (20.105 ktep of final energy consumption for 2015). To cover the electricity demand the plan says that 8 new Combined Cycle Thermal Power Plants and 1.800 MW from renewables will need to be built.

[30] the IER Scenario: reduction of 10,6% of Final Energy Consumption compared to Base scenario. It means a 1,74% annual reduction of energy intensity (final energy consumption/GDP) or a reduction of 2.137,8 ktep/year for the Final Energy Consumption, from which 20,9% comes from electricity. To guarantee supply 3 CCTPP and 4.500 MW from renewables will have to be added.

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	1,092	1,480	1,589
Biogas	264	1,365	1,397
Renewble waste	1,718	1,707	1,707
Biofuels	294	2,483	2,481
Biodiesel	63	2,254	2,254
Bioethanol	231	229	156
TOTAL	**3,368**	**7,036**	**7,173**
IER Scenario	**2003**	**2010**	**2015**
Forest & agricultural	1,092	2,104	3,240
Biogas	264	1,891	2,391
Renewble waste	1,718	1,939	2,312
Biofuels	294	4,393	9,817
thereof Biodiesel	63	4,151	9,134
thereof Bioethanol	231	242	683
TOTAL	**3,368**	**10,326**	**17,760**

Table 10: Use of biomass and biomass potential up to 2015. Source: Catalonian Energy Plan

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[31] 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.

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[31] Source: Dienhart, J. Nitsch; 2002

Plant Type	Resource	Electrical efficiency	Full load hours per year	installable capacity
Cogeneration	forest & agricultural biomass, biogas and renewable waste	30%	5,256	138.97
Power plants	forest & agricultural biomass, biogas and renewable waste	40%	5,256	185.29
			Subtotal	**324.26**
Cogeneration	biogas	30%	5,256	271.76
Power plants	biogas	40%	5,256	362.35
			Subtotal	**634.12**
Cogeneration	all fractions	30%	5256	410.73
Power plants	all fractions	40%	5256	547.65
			TOTAL	**958.38**

Table 11: Installable capacities for electricity production from biomass, considering different biomass fraction of the potential. Sources: SolCat II; 2009 and SolCat I; 2007 and as described in the Catalonian Energy Plan.

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 12 gives an overview of the potentials being used for scenario development.

Technology	**Potential (GW_{peak})**	**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 12: Overview of the potential considered for scenario development. Source: SolCat II; 2009, own calculation and data from Catalonian Energy Plan and Greenpeace “Renewables 2050.

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 to reach the same installed capacities, but already in 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[32]. 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, the annual investments necessary to achieve the scenario goals are calculated too. Assumptions regarding

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

the further development of specific investment costs for the different technologies are taken from the high variant of the Energy Watch Groups "Renewable Energy Outlook 2030"[33].

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 there have been own assumptions in the "Solar Catalonia I", this study refers to the cost development as described in the "Renewable Energy Outlook 2030" (REO 2030) study. As a result cost degression is lower if compared to the predecessor. No cost degression is assumed for hydropower (see Table 13).

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[33] Source: Stefan Peter, Harry Lehmann, Energy Watch Group, "Renewable Energy Outlook 2030; 2008. www.energywatchgroup.org, [EWG; 2008]

Technology	**Investment costs today [€$_{2006}$/kW$_{el}$]**		**Investment costs 2050 [€$_{2006}$/kW$_{el}$]**	
Biomass and Waste	4,325	(4,400)	3,595	(2,200)
Wind onshore	1,120	(1,200)	779	(600)
Wind offshore	1,669	(1,800)	962	(900)
Photovoltaics	4,288	(5,000)	1,504	(1,667)
Solarthermal Power	3,750	(4,000)	2,315	(2,000)
Geothermal Power	4,682	(8,000)	4,124	(4,000)
Hydropower[34]	5,000	(6,350)	5,000	(6,350)

Table 13: Specific investment costs today and by 2050, parenthesised values are the values used in “Solar Catalonia I”, SolCat II; 2009, based on data from “Renewable Energy Outlook 2030” and [Kruck/Eltrop; 2004].

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[34] Source: Christoph Kruck, Ludger Eltrop, Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER),„Stromerzeugung aus erneuerbaren Energien Eine technische, ökonomische und ökologische Analyse im Hinblick auf eine nachhaltige Energieversorgung in Deutschland“; 2004.

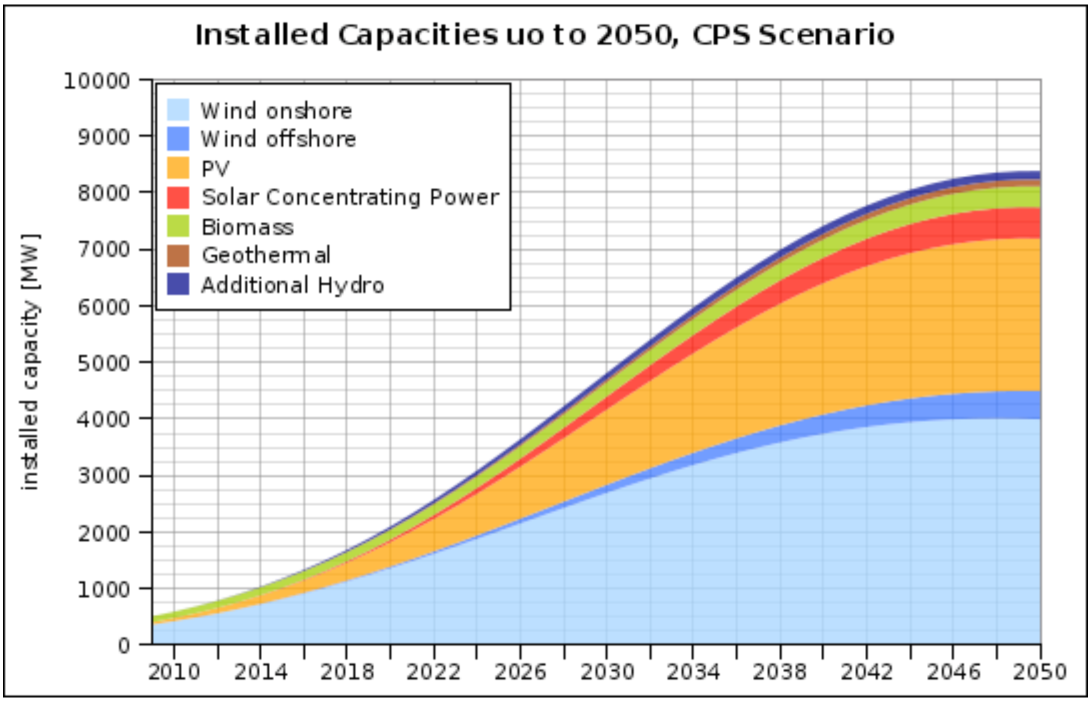
Introductory Scenarios

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 reach the same installed capacities in 2030 by 2030. With regard to the initial growth assumptions changes were made for wind energy and photovoltaics in relation to the "Solar Catalonia I" study. The results of the first simulation runs showed that wind energy capacities could be lowered and it was beneficial for the supply system to increase the capacity of photovoltaic systems.

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 28) increases to 4.7 GW by 2030 and further to 8.4 GW by 2050. Wind energy accounts for most of the new capacity (58% 2030 and 54% in 2050; onshore & offshore wind), followed by photovoltaics (28% in 2030 and 32% in 2050) and solar thermal power plants (5% in 2030 and 7% in 2050). Biomass, geothermal and additional hydropower's contribution to the generating capacity is substantially lower.



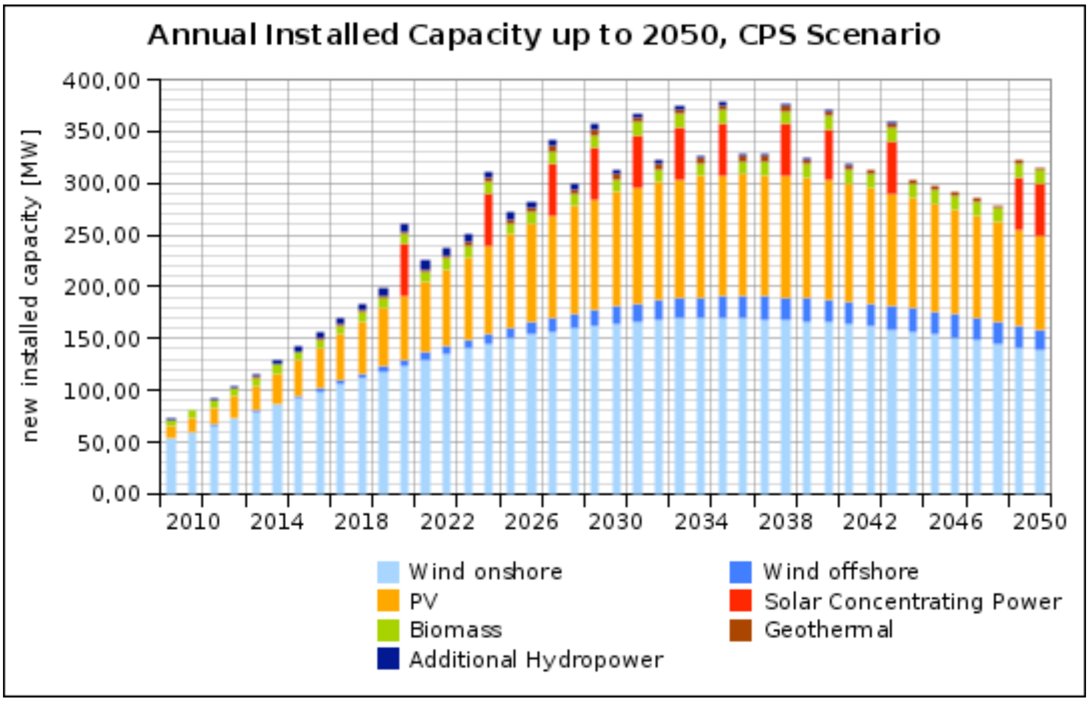
Picture 28: Climate Protection Scenario, Development of total generating capacities until 2050, SolCat II; 2009.

The share of adjustable technologies (biomass, geothermal & additional hydropower) drops by about one percent from 2030 to 2050; about 9% in 2030 and almost 8% in 2050 (see Table 14).

	Installed capacity [MW]				**Share of total capacity [%]**			
	2030		**2050**		**2030**		**2050**	
Wind onshore	2,573	(2,504)	4,006	(5,343)	55%	(65%)	48%	(62%)
Wind offshore	143	(123)	498	(532)	3%	(3%)	6%	(6%)
PV	1,329	(224)	2,694	(1,564)	28%	(6%)	32%	(18%)
Solar Thermal Power	232	(492)	550	(596)	5%	(13%)	7%	(7%)
Biomass elec.	251	(261)	373	(320)	5%	(7%)	4%	(4%)
Geothermal electricity	51	(135)	120	(173)	1%	(4%)	1%	(2%)
Additional Hydropower	115		150		3%	(3%)	2%	(2%)
Total	4,694	(3,855)	8,404	(8,678)	100%		100%	

Table 14: Climate Protection Scenario, installed capacities and shares at total renewable capacity, 2030 & 2050, parenthesised values are the values used in “Solar Catalonia I”, SolCat II; 2009, based on SolCat II; 2007.

Looking at the annual installed capacities (Picture 29, including plant replacement), a steady growth – up to 2036 – can be observed[35]. Afterwards annual installed capacities drops continuously as the further extension of RE capacities slows down. Nevertheless installing new capacities cannot not be reduced to zero after 2050 as the ageing of already installed plant requires a permanent replacement of such plants. This effect can already be observed much sooner for those technologies which have already been existent before 2009.



Picture 29: Climate Protection Scenario, Development of annual added generating capacities (including plant replacement) up to 2050. Source: SolCat II; 2009.

Basically the development up to 2030 is characterized by added capacities, while the share which is needed for plant replacement increases considerably in the aftermath (Picture 30). Consequently there is an increasing spread between the capacity getting installed year by year and the growth of total generating capacity[36].

The soonest start of plant replacement – without considering hydropower - is for biomass and wind energy, the (new) renewable technologies with the longest tradition in Catalonia.

Starting by about 2020 plant replacement is dominated by wind energy. Later on an additional considerable replacement requirement results from PV. Replacement of biomass, offshore wind energy and geothermal power remain on a relatively low level due to their low

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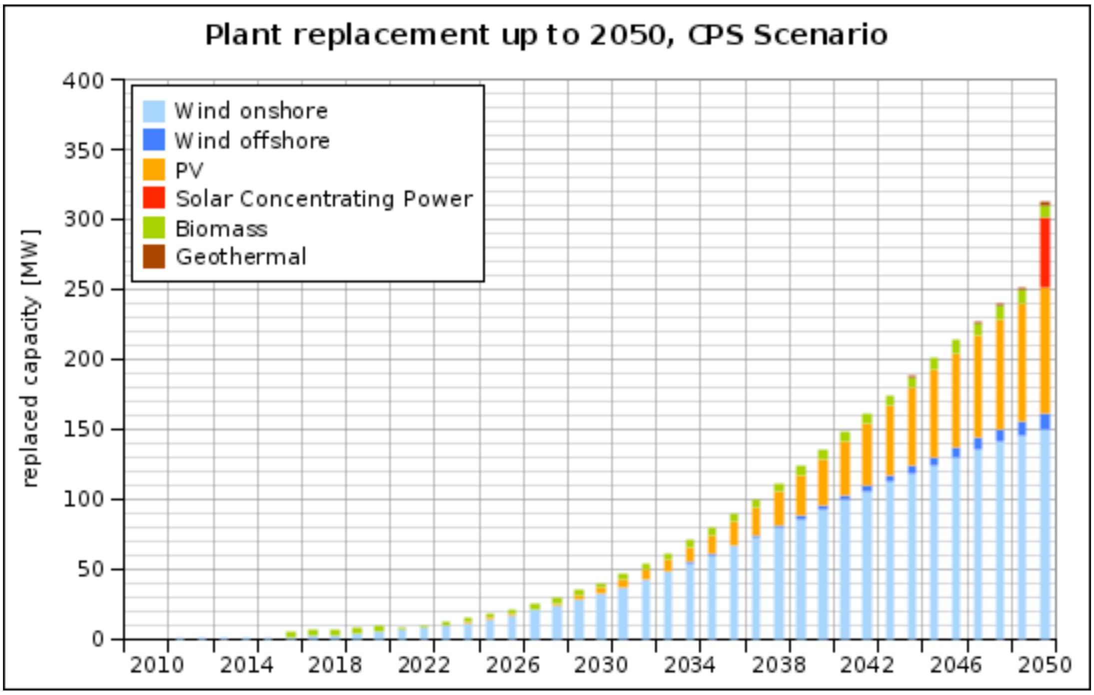
[35] Solar Concentrating Power is considered to be installed in units with 50 MW each. Therefore installation peaks occur each time a new SCP plant is built.

[36] Generally spoken plant replacement is a delayed “clone” of the earlier extension of capacities which must be managed in addition to the actual planned or desired capacity extensions.

contribution to the total of all generating capacities. In 2050 the first of the solar concentrating power plants will have to replaced (considering a life cycle of 30 years).

By 2050 plant replacement increases to about 150 MW for onshore wind energy, followed by PV (90MW) and SCP (50MW). Offshore wind energy, biomass (both about 10 to 11 MW) and geothermal power (about 2 MW) require much less replacements.



Picture 30: Climate Protection Scenario, Development of plant replacement up to 2050. Source: SolCat II; 2009.

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 highest levels of investment ever seen would – with a certain delay in time – occur again and again in certain time intervals, just to maintain the installed capacity. But we have to expect a decrease of technology costs, with the consequence, that capacity conservation gets cheaper with this reduction in costs.

Investment costs, low cost decrease (REO 2030, low variant)

With the lower costs reductions assumed in this study, the investment budget shows a peak bin 2034. By that time the total investment into renewable capacities is 525 million $€_{2006}$, which is about 62 $€_{2006}$ per inhabitant, if a further growth in population[37] – as projections indicate – is considered (see Picture 31).

After 2034 investments drop again until the total budget reaches a level of 396 million $€_{2006}$ in 2050, which is about 47 $€_{2006}$ per inhabitant Catalonia is projected to have by that time38. The further development of investments rely on several parameters, such as a further decrease in specific technology costs (this study does not make assumptions regarding costs after 2050) or if generating capacities shall be further increased beyond the capacities proposed in this scenario.

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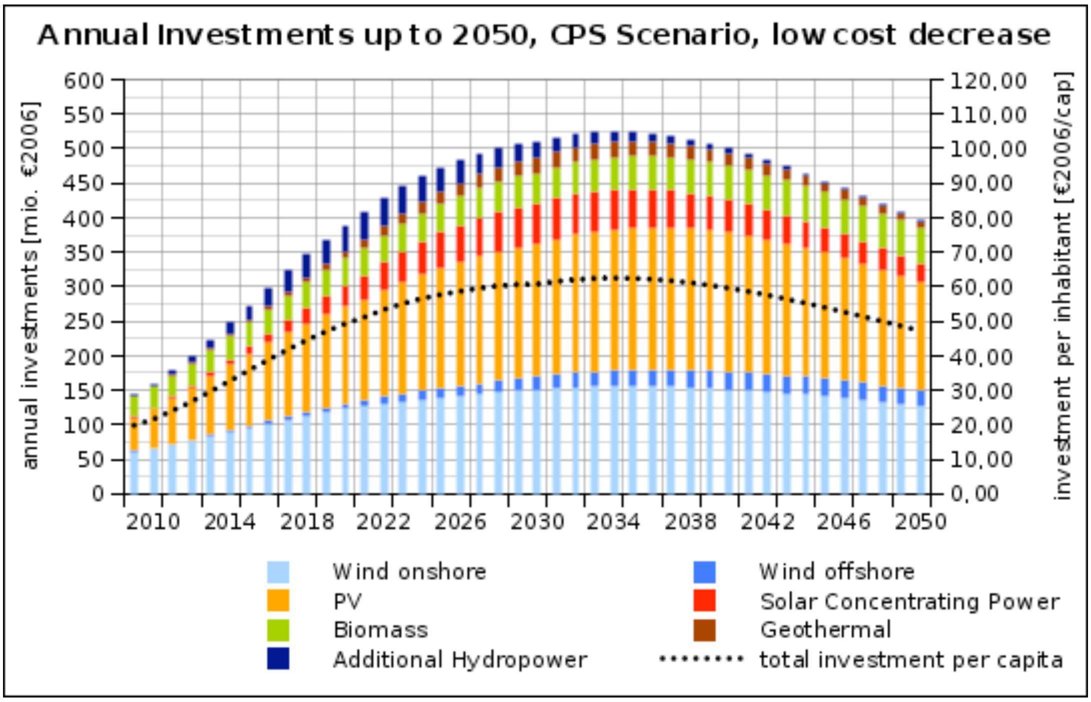
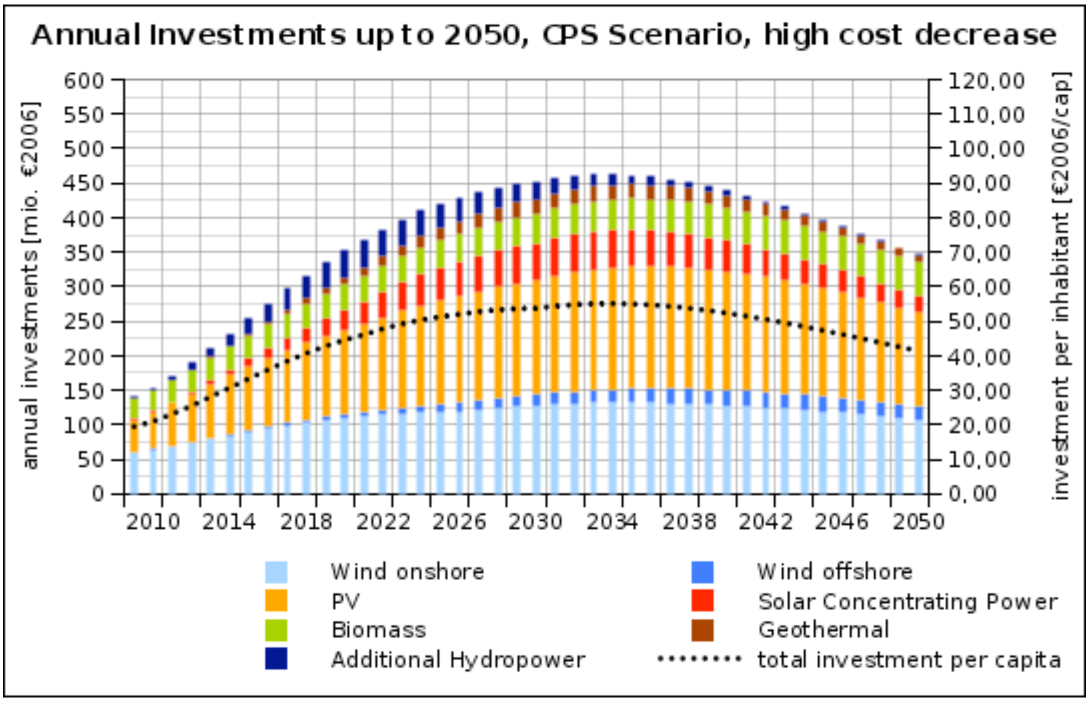
[37] Population projection from IDESCAT (www.idescat.cat/economia/inec?tc=3&id=8702&lang=en), medium high scenario.

[38] Projection from Institut d'Estadística de Catalunya indicates a population growth to 8.4 million by 2030; no further growth was assumed afterwards.





Picture 31: Climate Protection Scenario, Development of investments into renewable generating capacities at low cost decrease assumption (upper graph) and high cost decrease assumption (lower graph). Source: SolCat II; 2009, base on costs from “Renewable Energy Outlook 2030”.

Investment costs, high cost decrease (REO 2030, high variant)

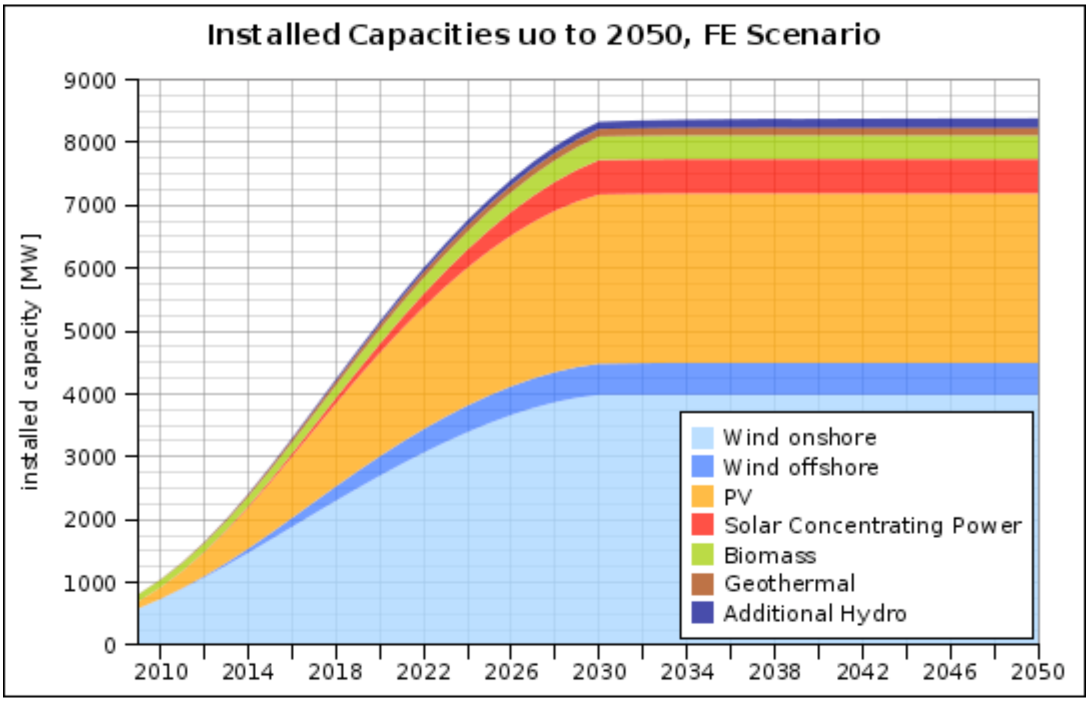
Considering a further development of technology costs as proposed in the “high variant” scenario of the EWG's “Renewable Energy Outlook 2030” results in lower investments for the extension of renewables in Catalonia along the path of the “Climate Protection” scenario.

While investment characteristics are almost the same as with the lower cost decrease (peaking in 2035 instead of 2034), investment in absolute term reduce to about 448 million $€_{2006}$ by that time (a reduction by 77 million €). In line with this per capita investment shows a peak level of about 55 $€_{2006}$ (minus 7 $€_{2006}$/cap). By 2050 total investments drop to 345 million $€_{2006}$ – about 51 millio $€_{2006}$ less than with the lower cost decrease – which means a per capita investment figure of 41 $€_{2006}$/cap (6 $€_{2006}$ less).

The “Fast Exit Scenario”

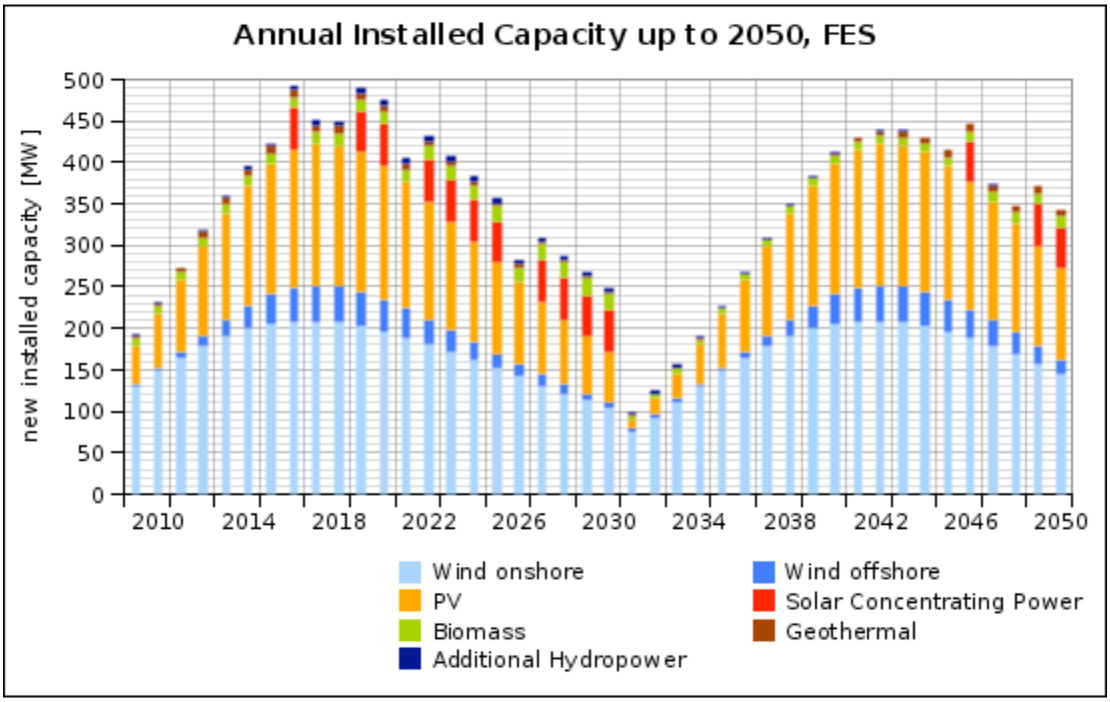
The “Fast Exit Scenario”(FES)aim to reach the same installed generating capacities as the “Climate Protection Scenario” (CPS) but speeds up development considerably: the 2050 capacities of the CP scenario will already be reached in 2030. Afterwards capacities remain stable – without any further increase – and new installed capacities reduce to pure plant replacement.

The new added generating capacities of renewables (Picture 32) increases to 8.4 GW by 2030 with no further increase until 2050. Mixture and share of technologies are the same as in the “Climate Protection Scenario” (CPS), but the whole period of extending capacities has been compressed to 21 years instead of 41 years.



Picture 32: Fast Exit Scenario, Development of total generating capacities until 2050. Source: SolCat II; 2009.

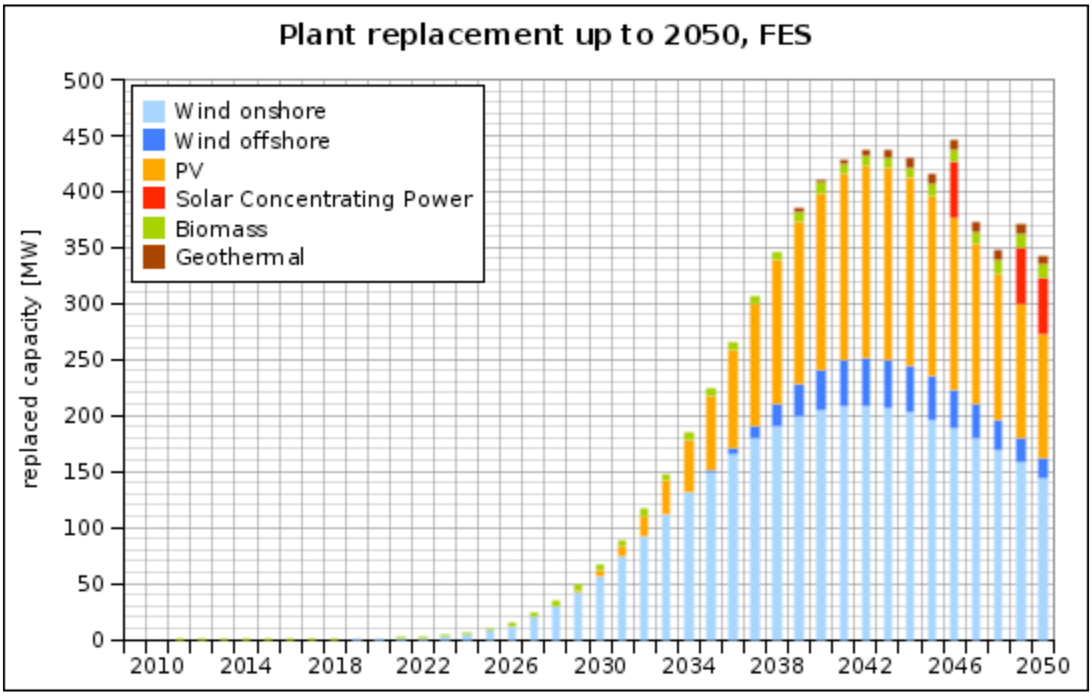
Looking at the annual new installed capacities (Picture 33, including replacement), annual additions are considerably higher than in the “Climate Protection Scenario. A peak of 487 MW new installed capacity, including the first 50 MW Solar Concentrating Power /SCP) plant, is reached in 2016 (a plus of more than 100 MW with regard to the CP scenario). Without SCP the peak occurs in 2017, with 444 MW. Afterwards new installation decrease rapidly towards 2030. After 2030 the effects of plant replacements become impressively obvious: the development from 2030 to 2050 resemble the previous development. But due to the different life cycles and the differing capacities that have already been installed before 2009 the development is not exactly the same. By 2050, e.g., all technologies with a 25 year cycle that have been installed before 2025 will be replaced. Also the three Solar Concentrating Power plant that have been built first will be replaced until 2050.



Picture 33: Fast Exit Scenario, Development of annual installed generating capacities up to 2050. Source: SolCat II; 2009.

In 2030 plant replacement almost exclusively falls upon wind energy (57 MW displaced capacity. As a result more than the half of the total new installed onshore wind capacity during that year is for plant replacement. Smaller replacement requirement fall upon PV and biomass, with less than 5 MW each.

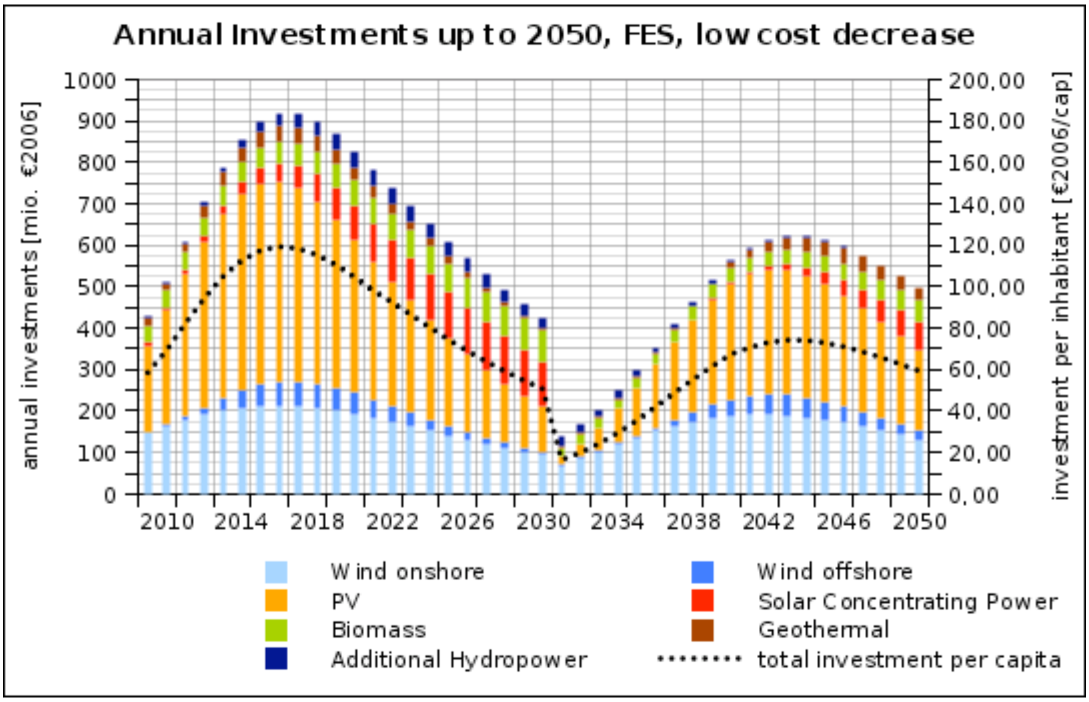
Until 2042 replacement increases to almost 450 MW with major contribution coming from onshore wind energy and photovoltaics. Basically replacement figures drop afterwards but single peaks result from compensating Solar Concentrating Power at the end of their life cycle.

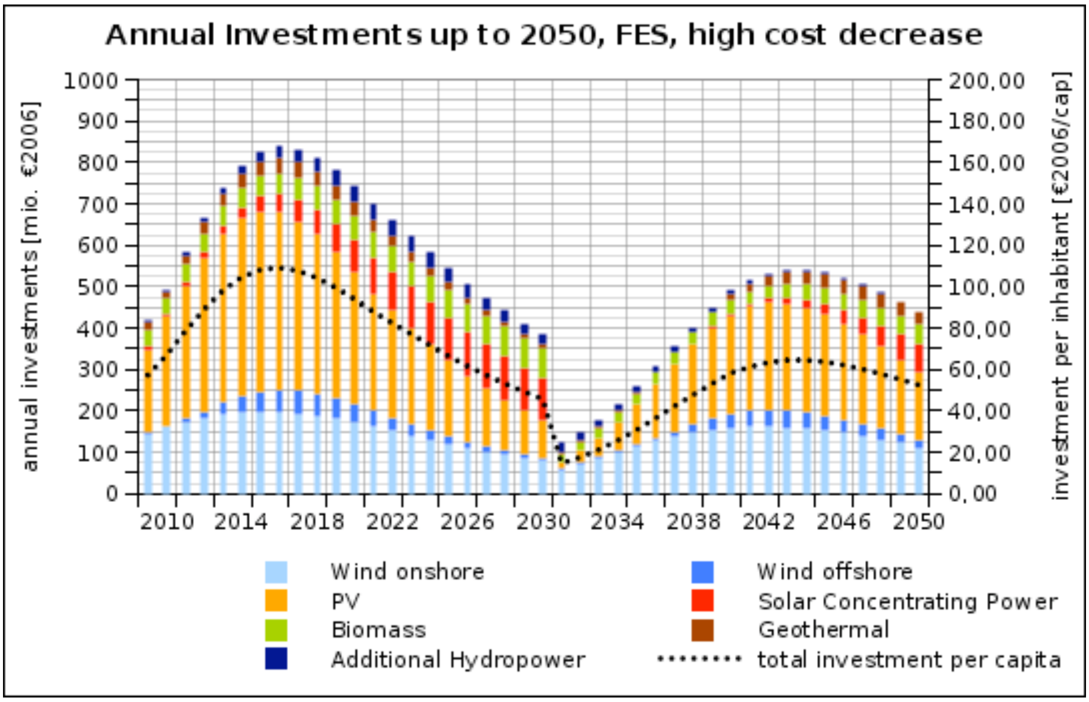


Picture 34: Fast Exit Scenario, Development of plant displacement up to 2050. Source: SolCat II; 2009.

The investment budget in the "Fast Exit Scenario" shows a peak around 2016. Afterwards investments drop and do not reach comparable levels again until 2050. As already described in the "Climate Protection Scenario" investment costs reduce quite much is assuming the higher decrease in technology costs. While there is a peak investment of about 917 million €$_{2006}$ with the low cost decrease assumption the related figure reduces to about 812 million €$_{2006}$ with the higher cost decrease. Concerning Catalonia's population by 2016 this investment figure is equivalent to 119 €$_{2006}$ (low cost decrease) respectively 109 €$_{2006}$ per inhabitant.

Although the capacities that have to installed to maintain the once achieved capacities is well comparable to the installation rates which were required to build up capacities, the decrease in specific technology costs make replacement much more cheaper. The peak investment for plant replacement is in 2043 and amount to about 624 million €$_{2006}$ with the low and to about 537 €$_{2006}$ with the high cost decrease assumption. Translated to investments per inhabitant and year this is equivalent to about 74 €$_{2006}$ (low cost decrease) respectively 65 €$_{2006}$ (high cost decrease). The next "replacement waves" will be cheaper again if we presume a further decrease in technology costs.





Picture 35: Fast Exit Scenario, Development of investments into renewable generating capacities. Source: SolCat II; 2009.

Conclusion

Both scenarios show the feasibility to achieve a fully renewable supply, one until 2046 (Fast Exit Scenario), the other until 2048 (Climate Protection Scenario). The bigger difference lies in reaching the target of an 80% supply from renewables: while the "Fast Exit Scenario" reaches this goal already in 2030, the "Climate Protection Scenario" achieves this target mark eight years later, in 2038.

Following one of the paths described in the scenarios 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 peak investment into renewable capacities of 109 $€_{2006}$ per inhabitant in the "Fast Exit Scenario" (2016) and 55$€_{2006}$/cap in the "Climate Protection Scenario" (2034), the financial burden to achieve a clean a climate friendly electricity supply in Catalonia is moderate in our point of view[39].(see Picture 36).

The development of investments differ a lot from the FES to the CPS: the FES shows a steep increase in the in the beginning, reaching peak investments already in 2016. Afterwards there is an almost as steep decline in investments up to 2031, followed by a re-increase which, in the further development, does by far not reach the peak value again (highest investments in the second half of development are about 65$€_{2006}$/cap in 2044). The characteristics of investments in the "climate Protection Scenario" is much more continuous. A slow rise until 2034 is followed by slowly declining investments. In 2050 the difference between the FES and the CPS is only about eleven $€_{2006}$ per inhabitant.

Considering average costs per inhabitant over the whole period the difference in much lower than the impression that might be created if only looking at the peak values. On average the costs per capita amount to about 65 $€_{2006}$ in the "Fast Exit Scenario" and to about 45 $€_{2006}$ in the "Climate Protection Scenario", a difference of only 20 $€_{2006}$ per inhabitant and year.

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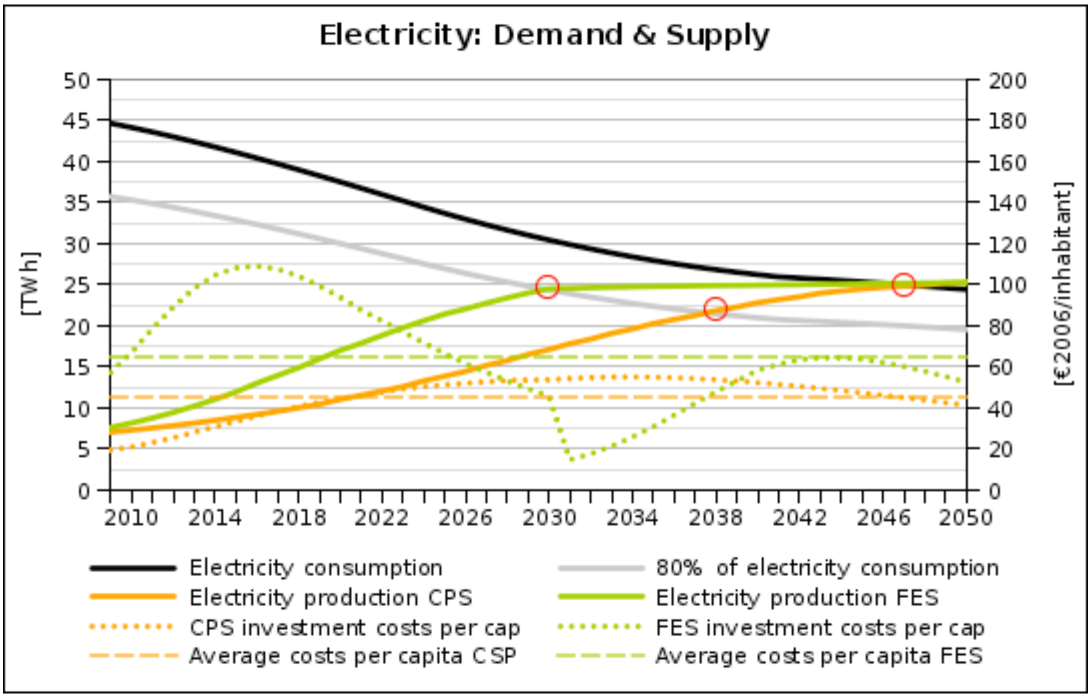
[39] Costs resulting with the assumption of high technology cost decrease. With the lower assumption peaks would be 119 $€_{2006}$/cap in the "Fast Exit Scenario" and about 63 $€_{2006}$/cap in the "climate Protection Scenario".



Picture 36: Development of electricity demand and supply in the scenarios. Source: SolCat II; 2009.

Compared to the Catalonian Gross Domestic Product (186,324 million € in 2008, on 2006 price base) the annual costs of the scenarios are 0.19 % of the GDP for the “Climate Protection Scenario” and 0.27 % 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][40]. 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

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

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

Assumptions & Settings of the Simulation

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.

Almost the same is true for the efficiency assumptions used here as, apart from individual behaviour, today's most efficient electrical appliances in the market often need less than the half of electricity as older devices or even as direct market competitors, offering the same service, comfort or functionality. Off course, additionally, there must be further progress in developing, marketing and installing more and more high efficient electrical appliances.

Scope and resolution of the simulation

The simulation covers one year with a time resolution of 1 hour. The simulation is done continuously, from the first to the last hour of the year. All underlying data, such as weather data and electricity demand data show the same time resolution of one hour.

Simulation approach

While the simulation in the “Solar Catalonia I” study was meant to prove that the paths described in the “Climate Protection Scenario” and the “Fast Exit Scenario” offer a realistic approach to a 100% Renewable Energy Supply in Catalonia's electricity sector, the successor (“Solar Catalonia II”) aims to present a more shaped version of the supply system. The supply system itself is set up to supply the electricity demand in 2050 according to the efficiency assumption used in this study.

An additional consideration was to design a “lower impact” system with reduced land use and less disturbance of the landscape. Therefore wind energy installations were lowered while more building integrated photovoltaic systems were used instead. The installed capacities of the other technologies remained unchanged but, in contrast to the “Solar Catalonia I” study, a reasonable amount of pumped storage plans were integrated. We do not assume additional land consuming constructions for the pumped storage plants but presume a conversion of existing hydropower plants into combined plants, offering additional power and storage capacity in order to improve supply security.

Electricity Demand

Referring to the efficiency assumptions made earlier in this study, annual electricity consumption in Catalonia can be reduced to 24 TWh, which is about half the electricity consumption of 2007. As the simulation needs the hourly variations in electricity demand a load profile, describing the hourly electrical load, was developed using the load profile for the whole of Spain, which are available via Red Electrica de Espana[41]. This load profile was transformed to represent Catalonia's electricity demand;

•The first step of transformation consisted of scaling the load profiles in such way that annual electricity demand and Catalonia's electrical peak load in November 2007 were met by the new profile;

•In a second step the efficiency assumption were applied to the scaled load profile;

•Finally assumptions regarding load shaping by Demand Side Management were applied; with the assumption that peak load (instantaneous power demand) could be reduced by 10% without changing the total annual demand (in terms of energy quantity).

The resulting load profile represents an annual electricity consumption of 24 TWh per year with a maximum power demand of 3,900 MW and a minimum of 1,840 MW[42].

The load profile used in “Solar Catalonia II” differs from the one used in the previous study as “Solar Catalonia I” referred to 2003 data. Although there are additional assumptions regarding Demand Side Management, the peak of the load profile used here is about 800 MW higher than it was in “Solar Catalonia I” (3,086 MW peak).

Analysis of the electricity demand data showed that maximum power demand per capita is higher in Catalonia than it is in Spain on average: while electricity demand in Spain (2007) shows a peak load of 0.98 kW/capita this figure is about one fifth higher in Catalonia (1.19

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[41] Data was provided by REE (Red Electrica de Espana).

[42] Electrical peak demand in Catalonia in November 2007 was 8,676 MW (el Economista; 2009, via internet on 2009/03/25: www.eleconomista.es/empresas-finanzas/noticias/341894/01/08/Demanda-electrica-en-Cataluna-crecio-42-en-diciembre-por-bajas-temperaturas.html)

kW/capita). The “efficiency load profile” for Catalonia shows a per capita peak load of 0.54 kW/capita, which is 55% lower than in Catalonia in 2007 or 45% lower if compared to the average in Spain in 2007.

Installed Capacities

The capacities installed in the simulation of “Solar Catalonia II” differ from the installation rates used in the previous work.

PV

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 45% of the total PV installations. Other substantial proportions are installed in the areas of Vallirana (16%) and Vacarisses (15%). Altogether the installed Capacity of PV results to 2,961 MW.

Installed PV capacities		
Weather data station	**Capacity [MW]**	**Share [%]**
Roses	2.1	0.08%
Cervera	4.6	0.17%
El Venderell	43.0	1,60%
L Espluga de Francoli	3.7	0.14%
Horta de Sant Joan	1.6	0.06%
Mas de Barberans	9.5	0.35%
Castellnou de Seana	8.6	0.32%
Torredembarra	134.8	5.01%
Font-Rubi	19.5	0.72%
Tarrega	67.9	2.52%
Vinebre	2.6	0.10%
El Perello	18.3	0.68%
Barcelona	1220.5	45.35%
Sant Salvador de Guardiola	38.3	1.42%
Organya	6.4	0.24%
Els Hostalets de Pierola	19.5	0.72%
Oris	20.6	0.77%
Clariana de Cardener	4.4	0.16%
Vallirana	423.0	15.72%
Vacarisses	401.3	14.91%
El Pont de Suert	2.7	0.10%
La Quar	8.2	0.30%
Das	4.8	0,18%
Angles	41.2	1.53%
Girona	62.0	2.30%
La Bisbal d Emporda	27.0	1.00%
Vilassar de Mar	78.1	2.90%
Olot	17.0	0.63%
Total	**2691.2**	**100.00%**

Table 15: Spatial Distribution of PV capacities (MW) used in the SimREN simulation; From Fast Exit Scenario 2050. Source: SolCat II; 2009.

Solar Concentrating Power

There are four regions that have been considered for installing Solar Concentrating Power (SCP) plants: the areas around Castellnou de Seana, Barcelona, Ulldemolins and Das. Most of the capacity is installed in the region of Barcelona (200 MW, 36% of total SCP capacity) and in the region of Castellnou de Seana, with 150 MW (27% of total). With an additional 100 MW each around Ulldemolins and Das the total SCP capacity results to 550 MW.

Installed Solar Concentrating Power		
Weather data station	**Capacity [MW]**	**Share [%]**
Castellnou de Seana	150	27.3%
Barcelona	200	36.4%
Ulldemolins	100	18.2%
Das	100	18.2%
Total	**550**	**100.0%**

Table 16: Spatial Distribution of Solar Concentrating Power capacities (MW) used in the SimREN simulation; From Fast Exit Scenario 2050. Source: SolCat II; 2009.

Wind Energy

The spatial distribution of Wind Energy plants was done by using the sites with good wind conditions and enough available area. Basically the distribution respects the areas restriction made in the Energy Plan. Another issue was the quality of meteorological data: as there have been numerous data sets with substantial gaps, i.e. longer periods showing errors, the number of used stations had to be restricted to those stations that contained sufficient valid data. To simulate the offshore windmills we used modified weather data from “El Perello”, a location at the southern coast of Catalonia.

The total installed capacity of wind energy results to 4,493,5 MW thereof 3,986 MW onshore and 497.5 MW offshore.

Installed wind power capacities, onshore				**[MW]**	**[%]**
Weather data station	**2,75 MW class**	**4,5 MW class**	**5 MW class**	**Total**	**Share**
Roses	148.5	292.5	295.0	736.0	18.5%
Cervera		108.0	105.0	213.0	5.3%
El Venderell		108.0	105.0	213.0	5.3%
L Espluga de Francoli	46.8	94.5	95.0	236.3	5.9%
Horta de Sant Joan		108.0	105.0	213.0	5.3%
Mas de Barberans			105.0	105.0	2.6%
Castellnou de Seana		121.5	120.0	241.5	6.1%
Torredembarra		121.5	120.0	241.5	6.1%
Font-Rubi	46.8	94.5	105.0	246.3	6.2%
Tarrega		94.5	95.0	189.5	4.8%
El Perello	46.8	94.5	95.0	236.3	5.9%
Das	148.5	292.5	295.0	736.0	18.5%
Vilassar de Mar		67.5	75.0	142.5	3.6%
Vila rodona	46.8	94.5	95.0	236.3	5.9%
Total	**484.0**	**1,692.0**	**1,810.0**	**3,986.0**	**100.0%**
Installed wind power capacities, offshore					
		V120 offshore	**M5 offshore**	**Total**	**Share**
El Perello (modified)		247,5	250,0	497,5	100%

Table 17: Spatial Distribution of Wind Energy Installation (MW) used in the SimREN simulation; From Fast Exit Scenario 2050. Source: SolCat II; 2009.

Adjustable Power Producers

Altogether adjustable power producers have a generating capacity of 4,200 MW, with the major part coming from hydropwer (2,477 MW, 59% of the total capacity of adjustable power producers including import[43]). Apart from the imported electrical power pumped storage plants (about 496 MW), biomass (373 MW) and geothermal power (120 MW) complete the ranking of adjustable producers.

Type	Capacity [MW]	Share [%]
Biomass	373.0	8.9%
Geothermal	120.0	2.9%
Hydropower	2477.0	59.0%
Pumped Storage	495.4	11.8%
Import (peak)	735.0	17.5%
Total	**4200.4**	**100.0%**

Table 18: Capacities of adjustable power producers and maximum import (MW) used in the SimREN simulation; From Fast Exit Scenario 2050. Source: SolCat II; 2009.

Results of the simulation

The results of the simulation show that, over the whole year, there is no point in time when electricity demand cannot be met. Due to the high share of fluctuating source, with only restricted storage facilities, there are often times with substantial surpluses in electricity supply, which might be exported. Imports are necessary too, but with a maximum import power of about 735 MW imports stay within a reasonable margin. Imports in the simulation are assumed to stem from electricity exchange with other regions in Spain and from France as well. Off course it would also be possible to extend generating capacities in Catalonia further in order to avoid any import. But increasing fluctuating supplier above the level described here would result in higher surpluses, which then would have to exported or to be stored in additional storage facilities. Additional adjustable suppliers, off course could handle this task but this would result in lower load factors; import occurs very seldom, thus the related capacity (if installed in Catalonia) would be used as seldom too. Another factor is that electricity supply systems with a high share of fluctuating supply benefit from strong connection with neighbouring regions as this makes handling fluctuations easier for the whole (nationwide or even international) supply area.

With regard to energetic balance the simulated system shows a total annual production of about 25.56 Terawatthours (TWh), which is about 6.7% more than the annual electricity demand (23.97 TWh). The surpluses should be exported to neighbouring regions. Total imported energy only contributes 0.05 TWh to electricity supply.

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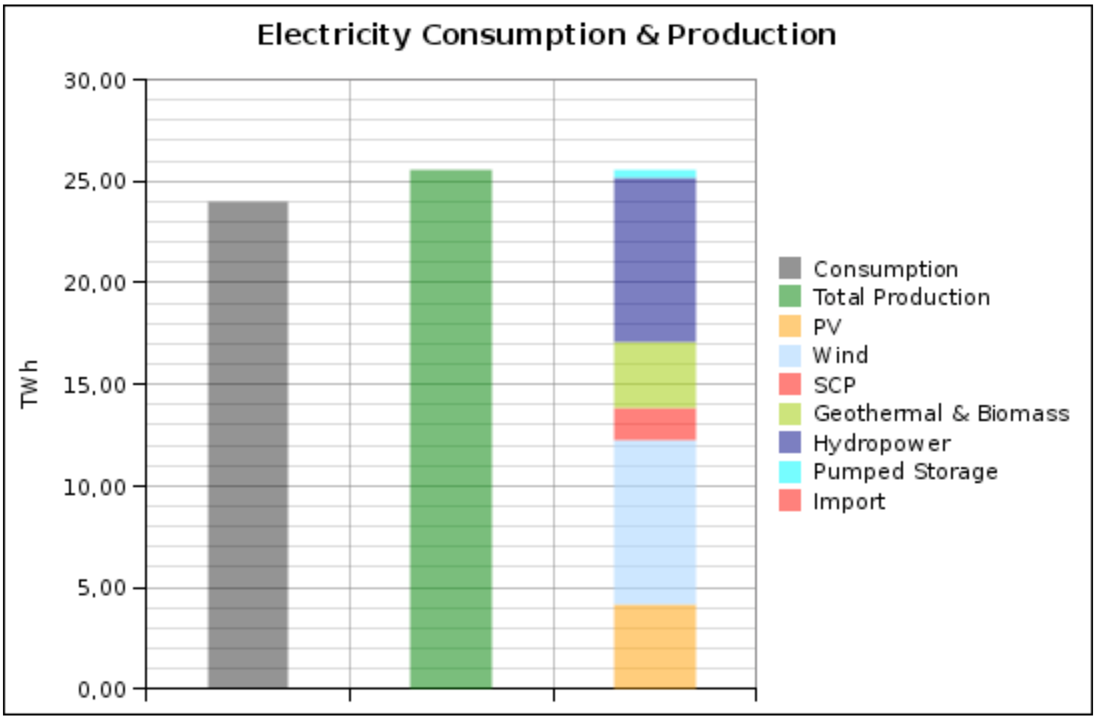
[43] Import does not represent an “installed capacity” but represents the simulation's result for maximum necessary import in the course of the simulated year.



Picture 37: Electricity consumption in 2050 and electricity production of the simulated supply system. Source: SolCat II; 2009.

Considering the annual variations in the different technologies contribution to supply some general trends can be observed (see Picture 38)[44]: Fluctuating suppliers show a varying performance, depending on the season (upper an middle graphs). This characteristic is clearly affected by the high share of solar driven technologies and their constitutional seasonal variations. Wind energy performs best during late winter and early spring, remains on medium level until late summer but drops considerably then. Late autumn again shows day with higher wind energy performance on occasion.

The distinct seasonal variations of the fluctuating part of the supply system force the adjustable part of electricity supply to show a contrary behaviour: Hydropower. Geothermal & Biomass and Imports have to contribute more during autumn and winter.

The third graph shows the activity of pumped storages. Basically pumped storages activity increase with an increasing supply by fluctuating suppliers.

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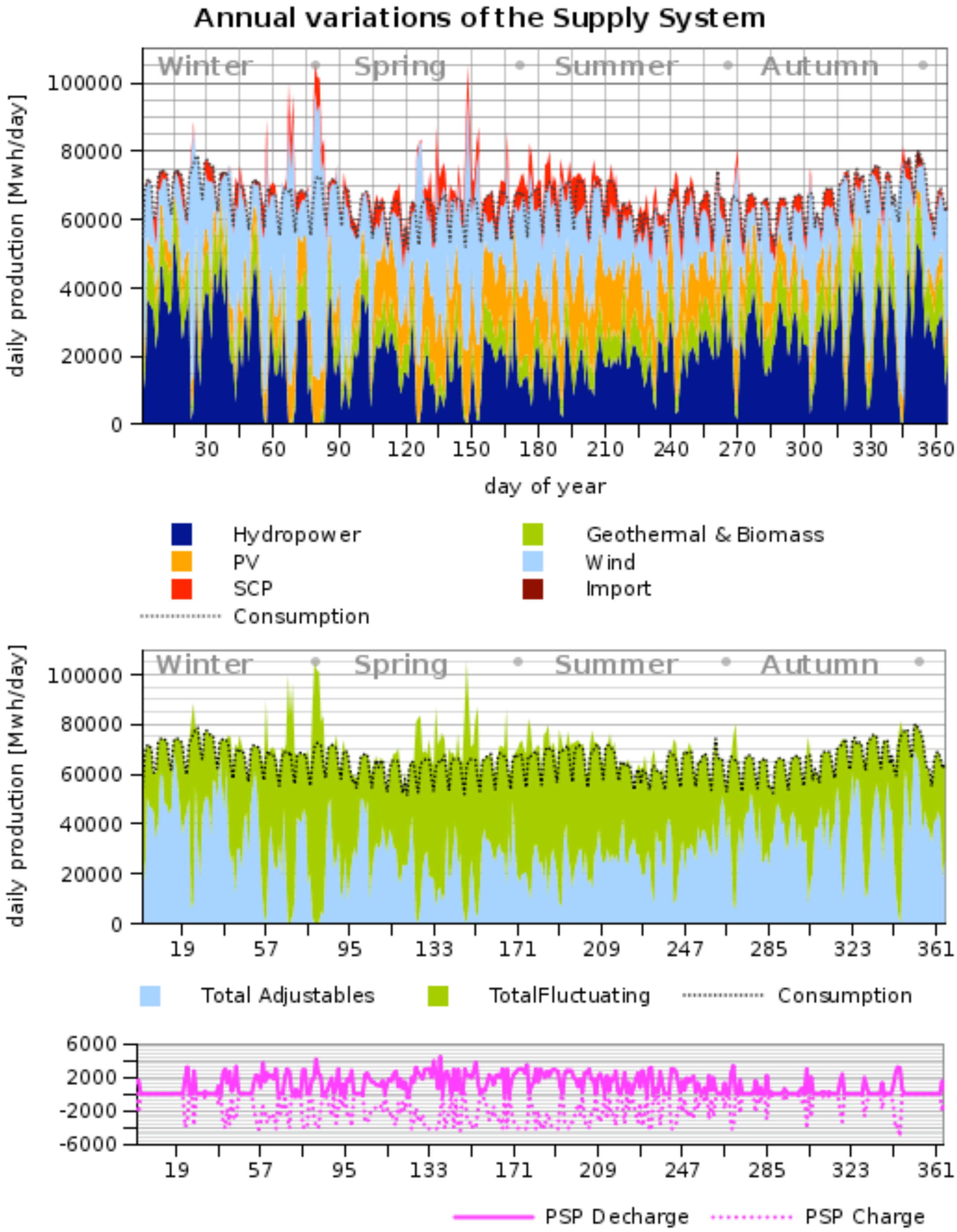
[44] Each data point shows the total electricity production (MWh) for one day for the related technology.



Picture 38: Annual variations of the supply system during the simulated year, average power for each day of the year. Source SolCat II; 2009.

To get an impression of the way the supply system works on an hourly base, the following section will present some graphs, each showing two consecutive weeks. The remaining graphs for all two week periods of the year can be found in the annex. (see also: Annex)

The first two week of the year

The system dynamics of the year's first two weeks (see Picture 39) shows that electricity demand (black line in first graph) is always fulfilled by the system's production (red line in first graph). Only the early morning of the second day shows a production that exceeds demand. This is the result of of a relatively high production of wind energy (see light blue line in third graph). Basically adjustable suppliers (blue line and area in second graph) contribute most to electricity supply during these two weeks. However there are some periods when fluctuating suppliers (green line and area) contribute more than the adjustable ones.

Supply security heavily depends on hydropower (dark blue in third graph), which is the main contributor, and geothermal & biomass (green line in third graph), both running at full power almost all the time. On occasion there is an additional need for electricity import (dark red line).

Apart from the first hour of the year[45], pumped storage plants (fourth graph) are only active after wind energy caused surpluses that could be used to refill storages. The following decrease of fluctuating supplier's electricity production causes a prompt complete discharge of storages which cannot be refilled during the remaining period.

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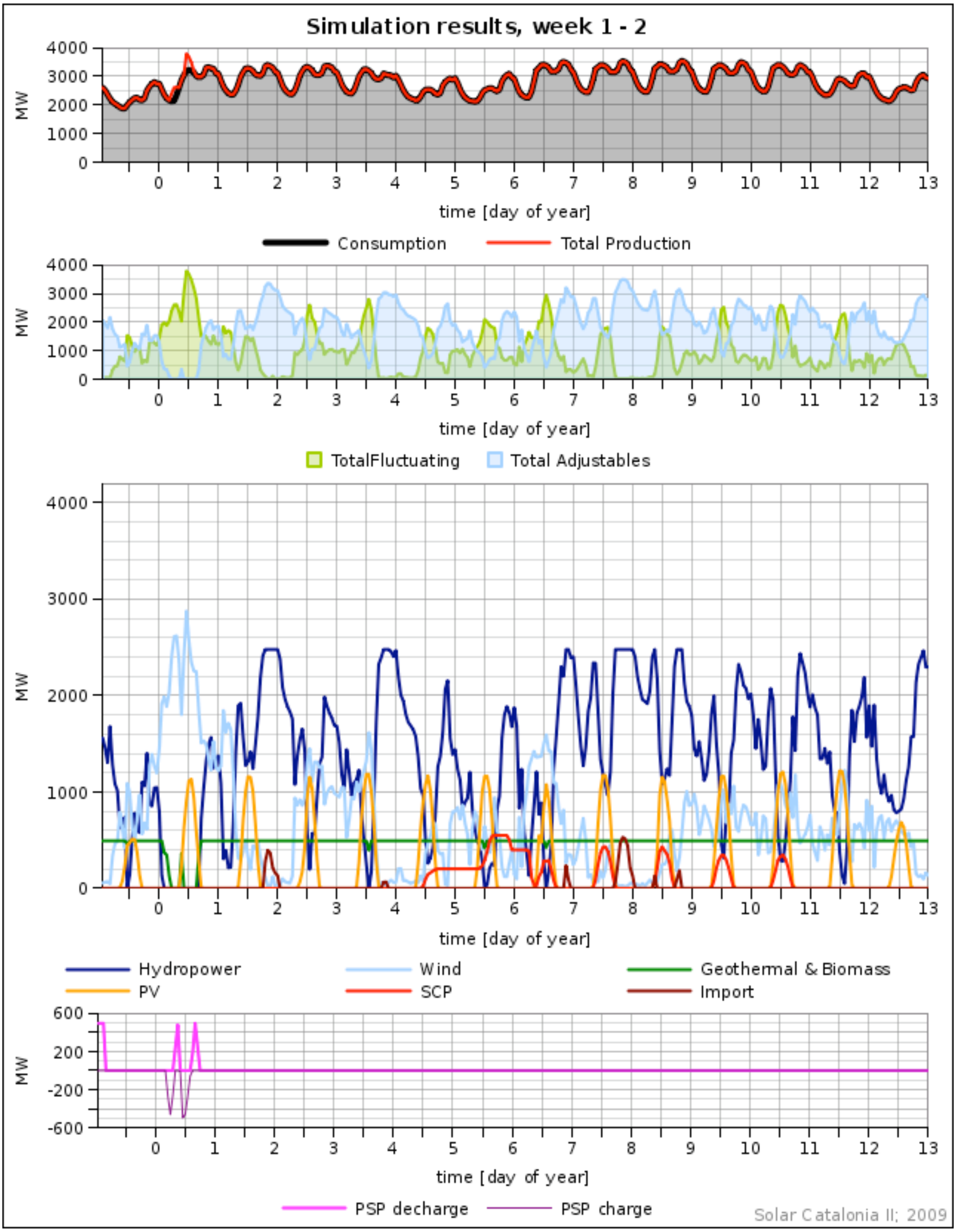
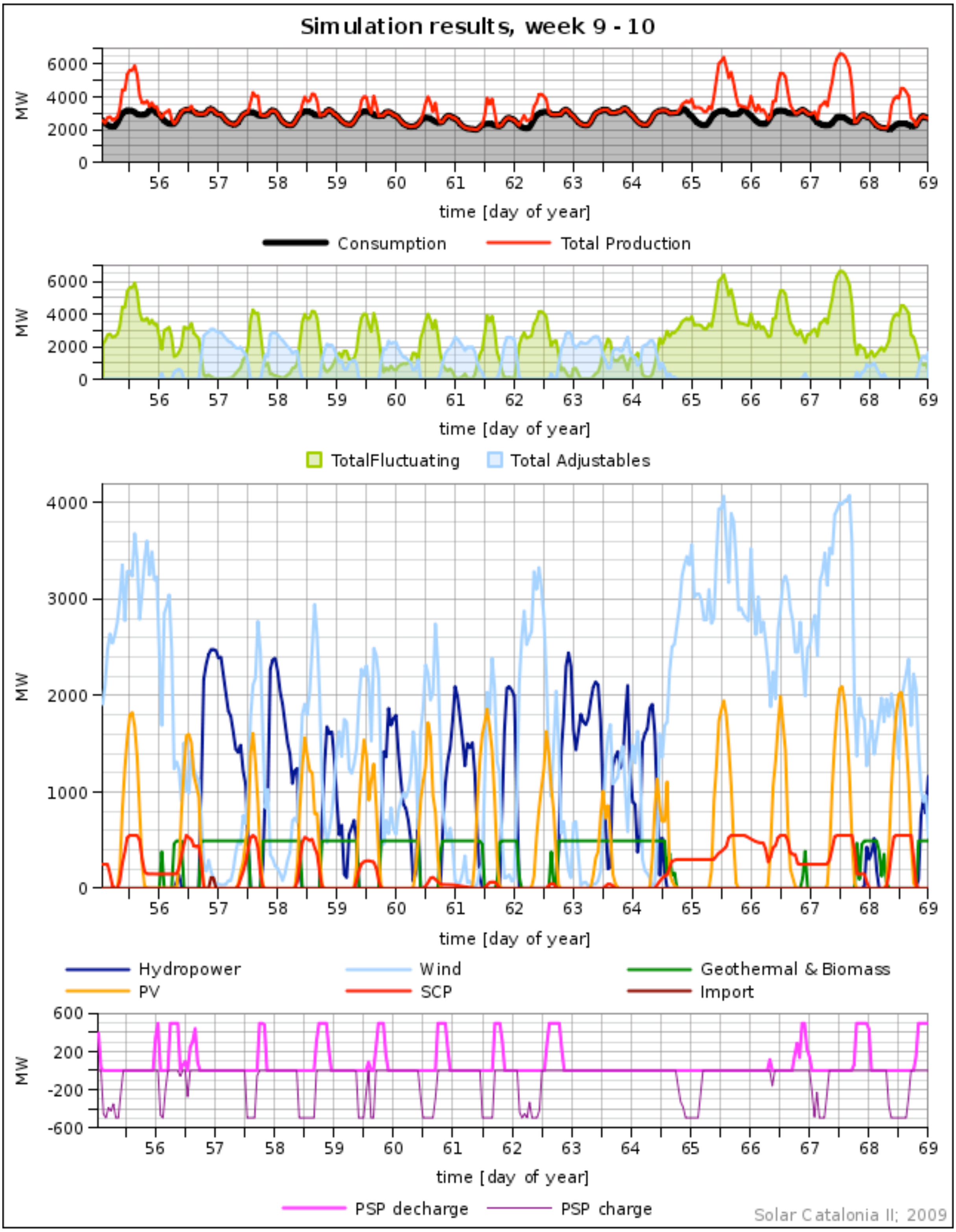
[45] Storages of pumped storage plants have been set to a half-full state at the beginning of the simulation.



Picture 39: Results of the simulation for the first two weeks of the year. Source: SolCat II; 2009.

February/March - Weeks nine and ten

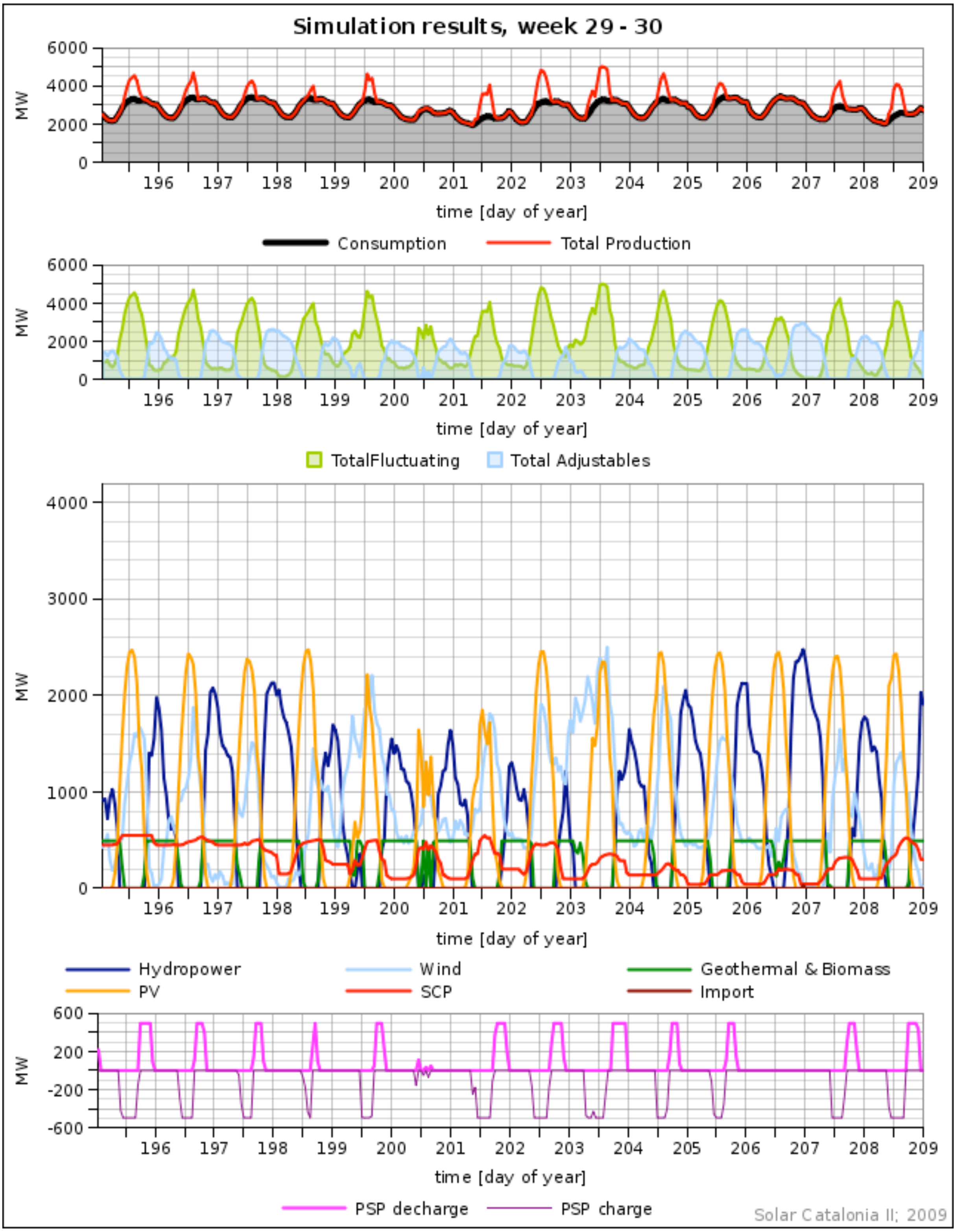


Picture 40: Results of the simulation for one week in summer. Source: SolCat II; 2009.

Weeks nine and Ten (February/March, see Picture 40) show more times with electricity surpluses due the electricity production of fluctuating suppliers, if compared to the beginning of the year. Again, there is no situation when electricity demand is higher than supply. During this two week period most of the electricity is supplied by fluctuating renewables. Additionally there are several longer period without any need for adjustable suppliers.

It is not only wind energy showing a much better performance than in weeks one and two. The increasing power of the sun also causes a higher productivity of photovoltaics and solar concentrating power. The surpluses in electricity production do often offer good operation conditions for pumped storage plants, which show much more activity than at the year's beginning.

Mid of July – Weeks 29 and 30

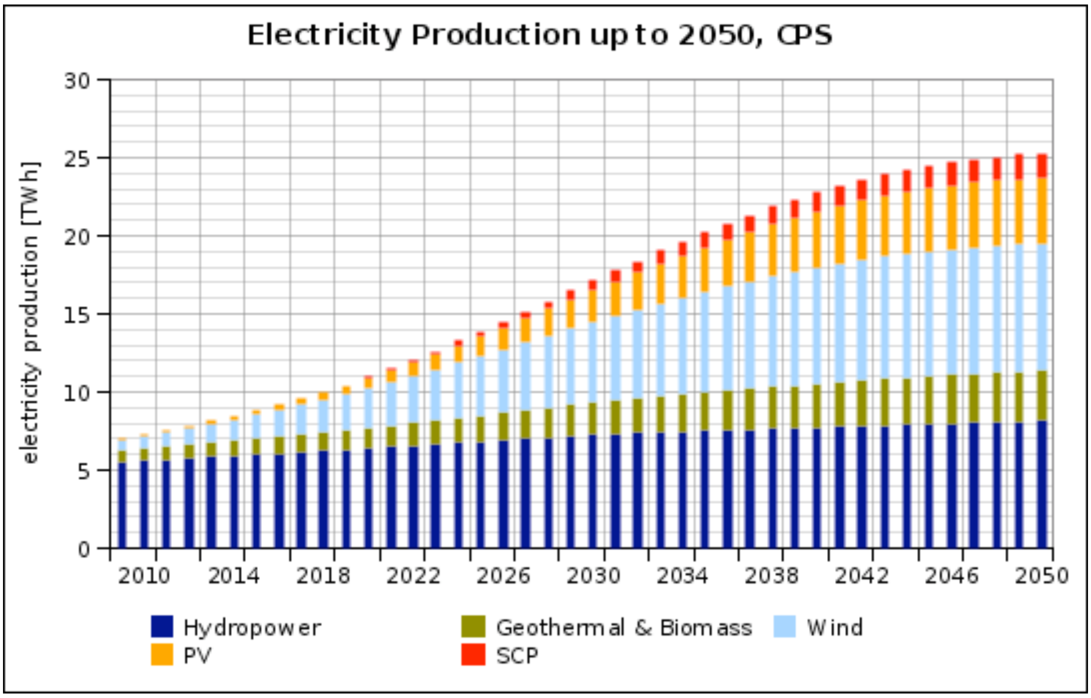


Picture 41: Results of the simulation for one week in autumn. Source: SolCat II; 2009.

Mid of July is clearly affected by solar electricity (see Picture 41). Good solar conditions result in electricity surpluses around noon on almost every day during this two weeks. Wind speed varies quite much and peak in wind speed show a strong correlation with solar irradiation. Pumped storages can be recharged regularly using the mid-day surpluses. In the afternoon pumped storages contribute to electricity supply and extend the period without need for adjustable suppliers. Considering electricity supply as a whole, demand can always be guaranteed. There is no need for electricity imports over the whole period.

Development of electricity generation by renewable technologies.

Electricity generation in the “Climate Protection Scenario” (see Picture 42) increases from virtually only the existing hydropower plants contribution to 17,12 TWh in 2030 and 25.26 TWh in 2050. Comparing this production figures to the electricity demand projection, as described in the “Energy Demand Module” (31 TWh in 2030 and 24.43 TWh in 2050), about 55% of the total Catalonian electricity demand can be covered by renewably produced electricity in 2030. Until 2050 this figure increases to 103%[46].



Picture 42: Climate Protection Scenario, Development of electricity production from renewables, up to 2050. Source: SolCat II; 2009.

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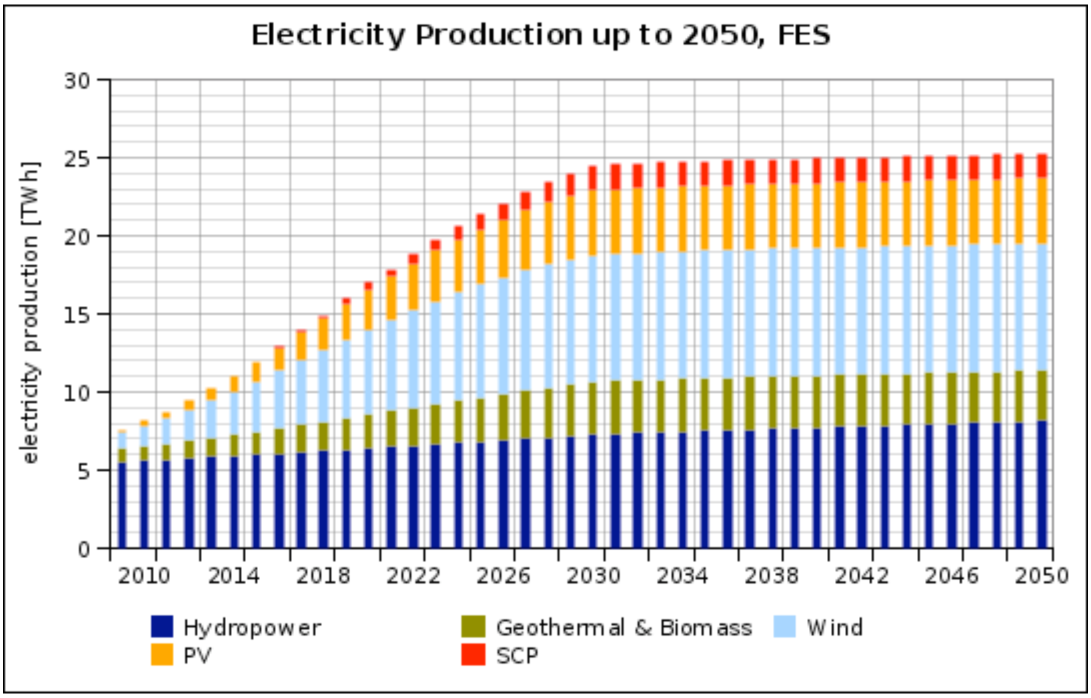
[46] The electricity production in this section is calculated by average annual full load hours on base of the simulation's results for the 2050 model.

Electricity generation in the “Fast Exit Scenario” (see Picture 43)increases from virtually only the existing hydropower plants contribution to 24.52 TWh in 2030 and remains almost stable afterwards (25.28 TWh in 2050). Comparing this production figures to the electricity demand projection, as described in the “Energy Demand Module” (31 TWh in 2030 and 24.43 TWh in 2050), more than 78% of the total Catalonian electricity demand can be covered by renewably produced electricity in 2030. Until 2050 this figure increases to 103%, the same values as in the “Climate Protection Scenario”.



Picture 43: Fast Exit Scenario, Development of electricity production from renewables, up to 2050. Source: SolCat II; 2009.

Conclusion

The continuous simulation of electricity demand and supply for the whole year demonstrates that the system can always guarantee a secure electricity supply in Catalonia. From late winter to the beginning of autumn fluctuating suppliers play the dominant role. There are even several days without any need for adjustable suppliers. Imports are still necessary to always fulfil the demand for electricity but the instantaneous needed power as well as the total mount of imported electric energy remain on a low level. The characteristic of wind speed and solar irradiation combine quite well, at least during the simulated year: best wind condition are in late winter/ early spring, the time the sun is till not powerful enough to drive solar technologies to their maximum capacity.

From autumn to late winter the adjustable suppliers have to contribute most to electricity supply, as the decrease in solar irradiation appears in conjunction with generally lower wind speeds. Looking at the big picture the climate variation over the year, with strong wind performance especially in late winter/early spring, good solar and medium 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 utilization 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.

We do not refuse the statement of the “Solar Catalonia I” study that a full renewable electricity supply could be established much sooner (around 2035); indeed the “Fast Exit Scenario achieves a 87% renewable supply by that time. But we try to address clearly that a full renewable electricity supply depends as well on sufficient and diversified generating capacities as it depends on increasing energy efficiency. Generally this study makes the same assumptions regarding future efficiency improvements but we additionally included a possible further economic development instead of assuming “zero growth” as the predecessor did and the new starting point (2009) shows a higher electricity consumption. Together these factors slow down the progress in electricity demand reduction in comparison to the “Solar Catalonia I” study. In total electricity consumption in this work drops to 55% of the 2009 level until 2050. Although this might seem very much this is only about 5% less than the consumption in 1993, which is a conservative approach to energy efficiency in our point of view. The related annual decrease is slightly less than 1.5% per year, which is perfectly in line with the efficiency improvement demanded by the EU's “Action Plan for Energy Efficiency”. Further going reduction are possible from the technological perspective but this also depends on the further economic development – at least as long as we do not manage to decouple energy consumption from the GDP's development – and the effort and the investments we spend for increasing energy efficiency.

Achieving full renewable supply sooner as described here will be a triad of RE capacities, energy efficiency and the imports – whether renewable or not – that are accepted during the period of transition. Two of these parameters, faster extensions of RE capacities and faster implementation of efficiency improvements, can directly be used to lower electricity imports and generating capacities necessary for supply; it is up to the Catalonian people and the Catalonian administration to decide what is the best option for them and what they are willing to invest.

Right now we are living in times when Climate Change is widely accepted as a serious thread and even more and more electronic companies, e.g., discover energy efficiency as a key feature for their products. Energy efficiency was a big issue on the latest IFA consumer electronics exhibition in Berlin. Many producers announced new devices with half the electricity demand as their predecessors. The introduction of energy efficient technologies into the mass markets we actually see will help in opening up an opportunity to increase energy efficiency even faster than assumed in this study. Off course this will also depend on the further absolute increase of electricity consuming devices, as there is no gain if we half electricity consumption and double the amount of devices in parallel. Bringing down electricity consumption to sustainable levels will also include the question if we need two or more television sets in one household etc.

Policy Module

In the previous study, Solar Catalonia I, we described the framework of energy policies that Catalonia has adopted since the early eighties. So, we will nor repeat them in this new study.

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.

Annex

26 Pictures of the simulation for the whole year (provided separately)

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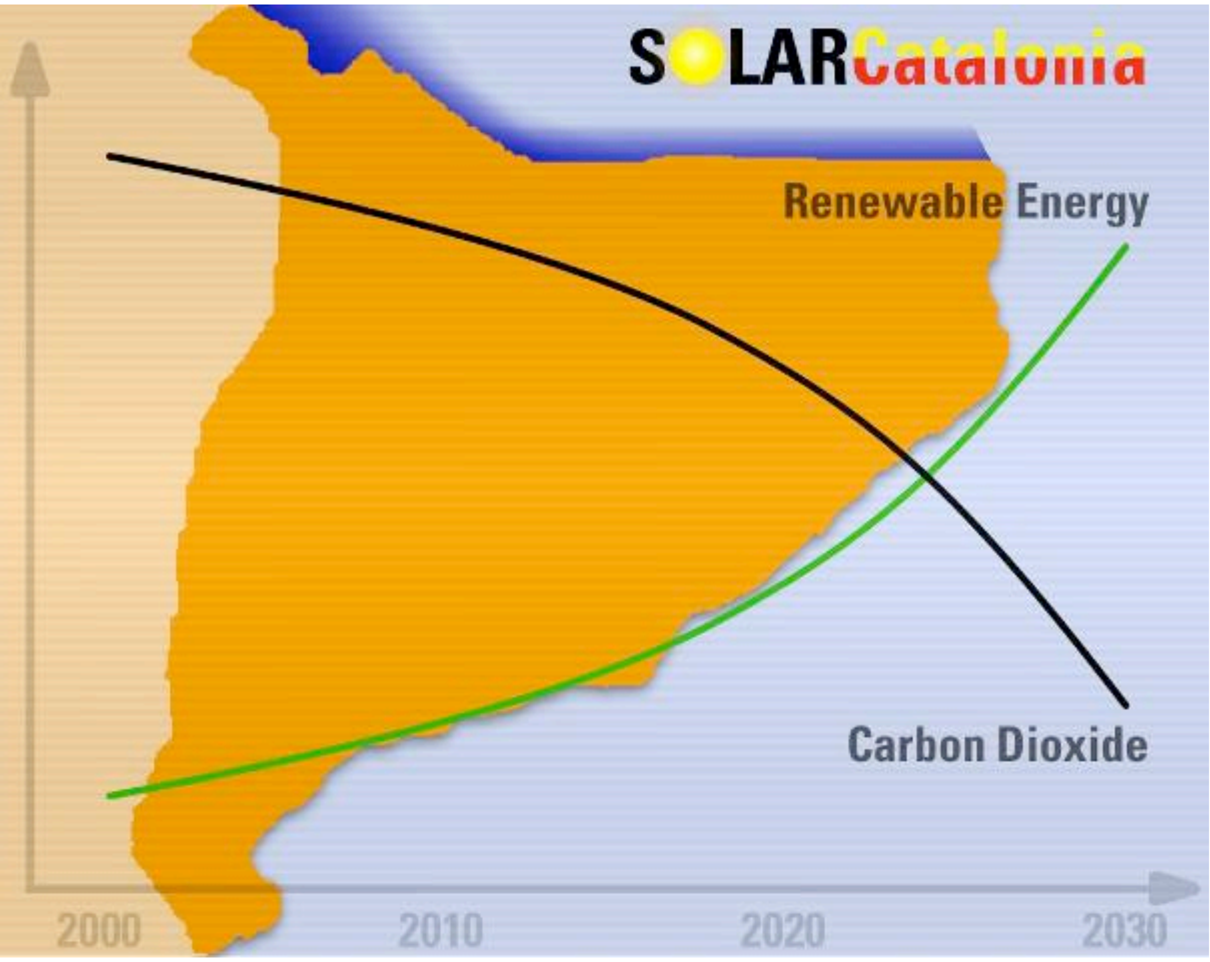
Solar Catalonia II

A Pathway to a 100% Renewable Energy System for Catalonia

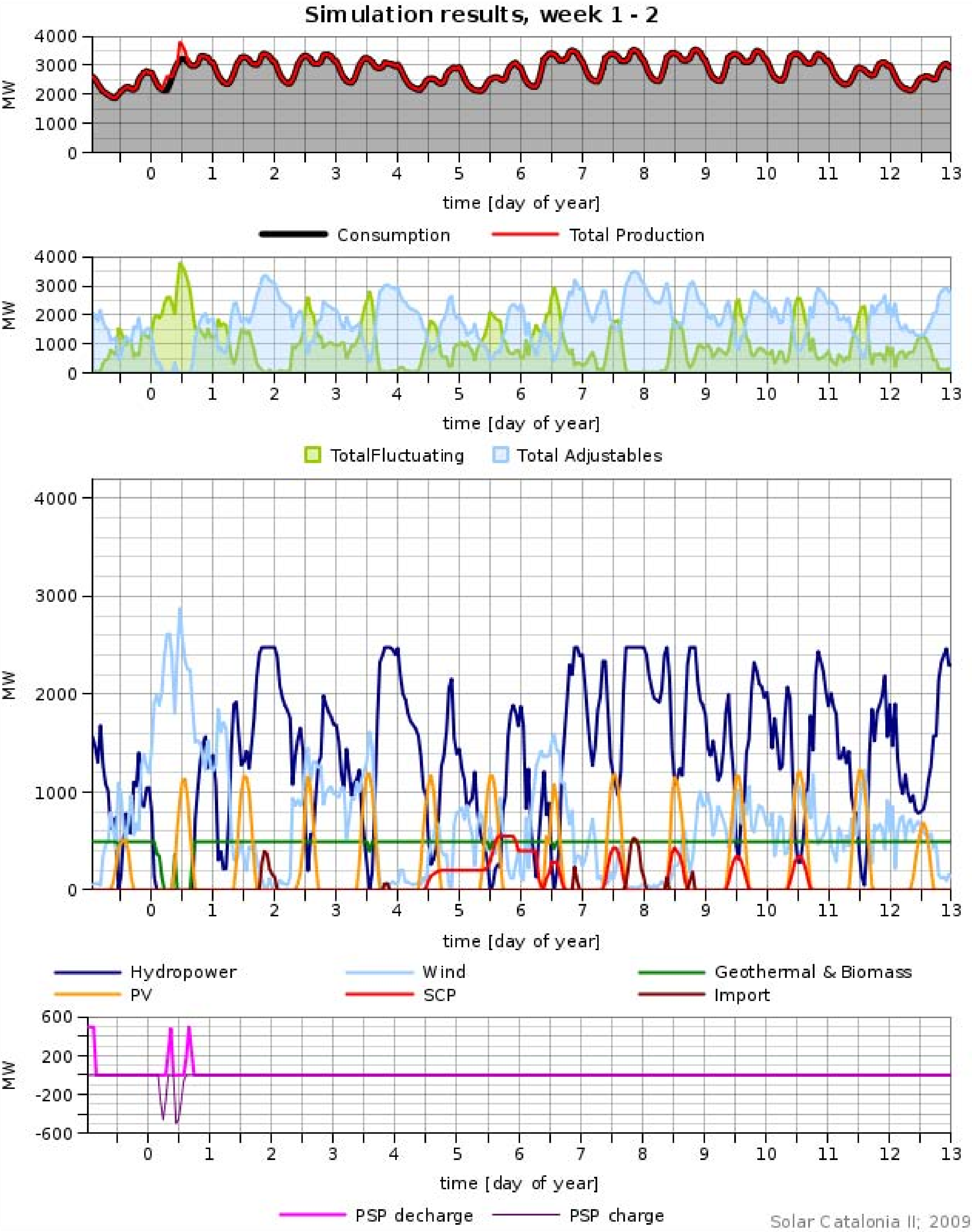
A simulation of Catalan electric system based on the analysis of the hourly meteorological data and electricity load's profiles for 2007. Annex



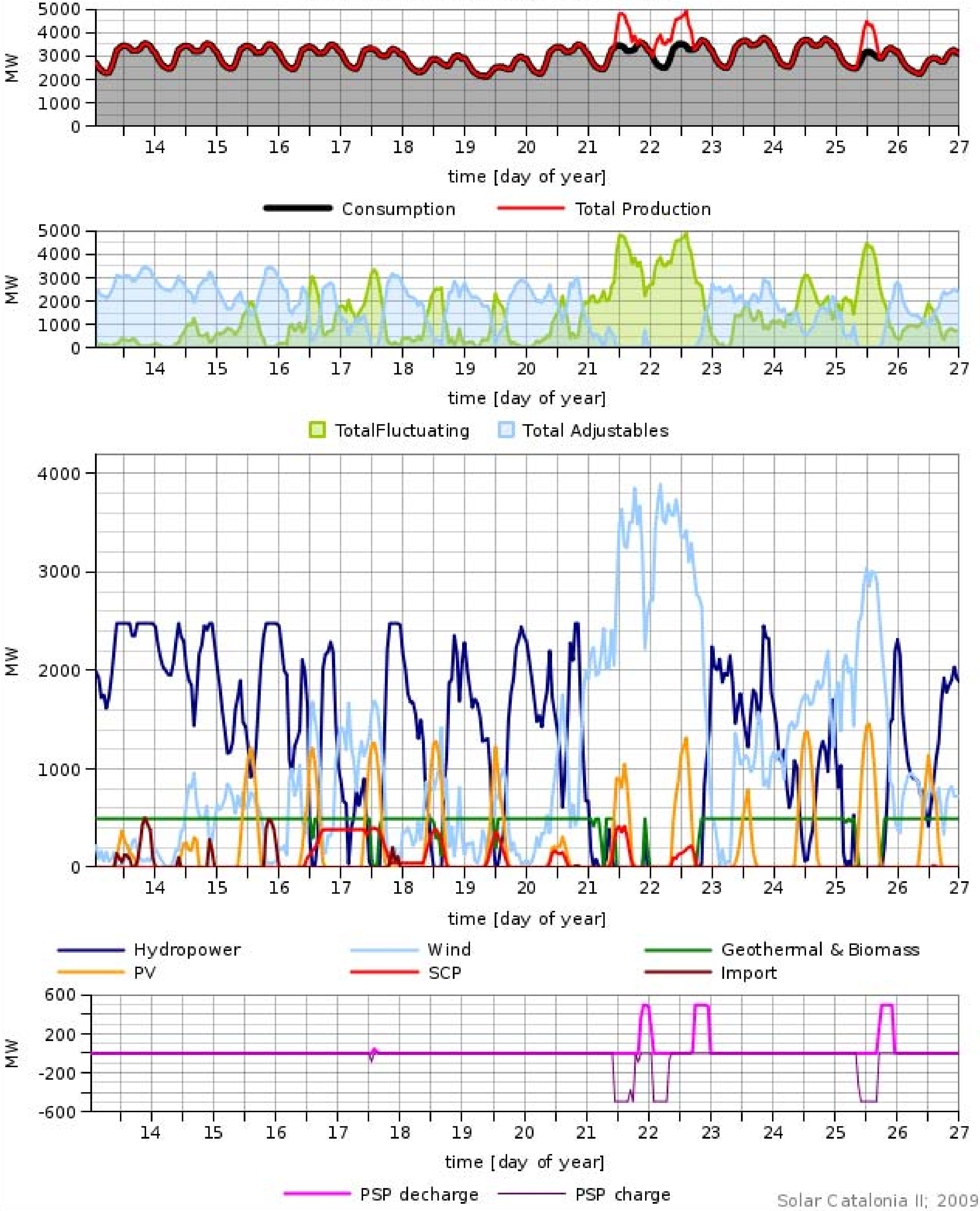
Barcelona / Makkleeberg, 2009

Authors: Stefan Peter[1], Harry Lehmann[2], Josep Puig[3], Marta Garcia[4]

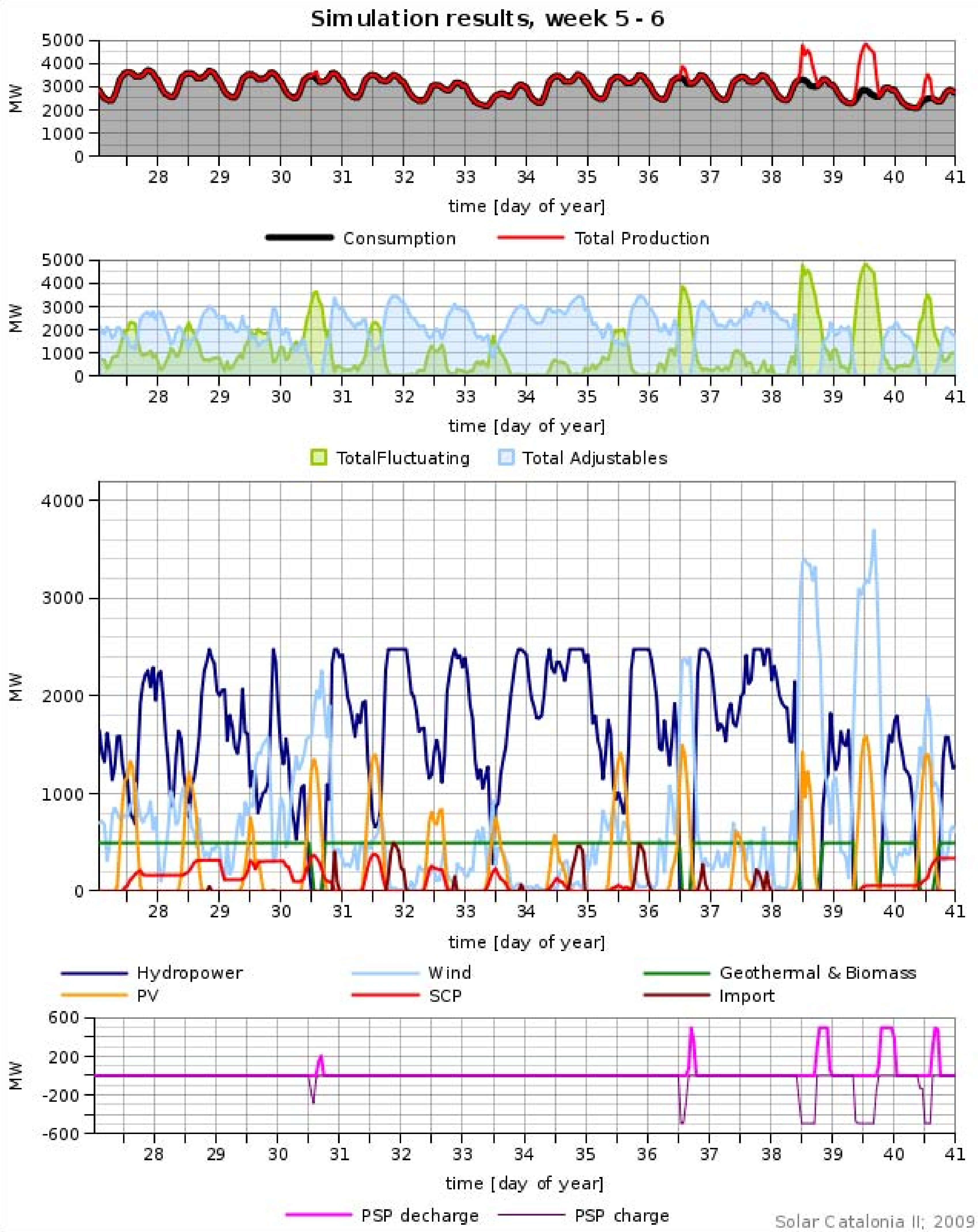
[1] **iSUSI** – Institute dor Suistainable Solutions and Innivations, www.isusi.de
[2] **WCRE** – World Council for Renewable Energy, http://www.wcre.de/en
[3] **Eurosolar** – European Association for Renewable Energy, www.eurosolar.org
[4] **Ecoserveis** – www.ecoserveis.net


Simulation results, week 1 - 2
MW
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
time [day of year]
Consumption
Total Production
MW
4000
3000
2000
1000
0
time [day of year]
TotalFluctuating
Total Adjustables
MW
4000
3000
2000
1000
0
time [day of year]
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
MW
600
200
-200
-600
time [day of year]
PSP decharge
PSP charge
Solar Catalonia II; 2009

Simulation results, week 3 - 4

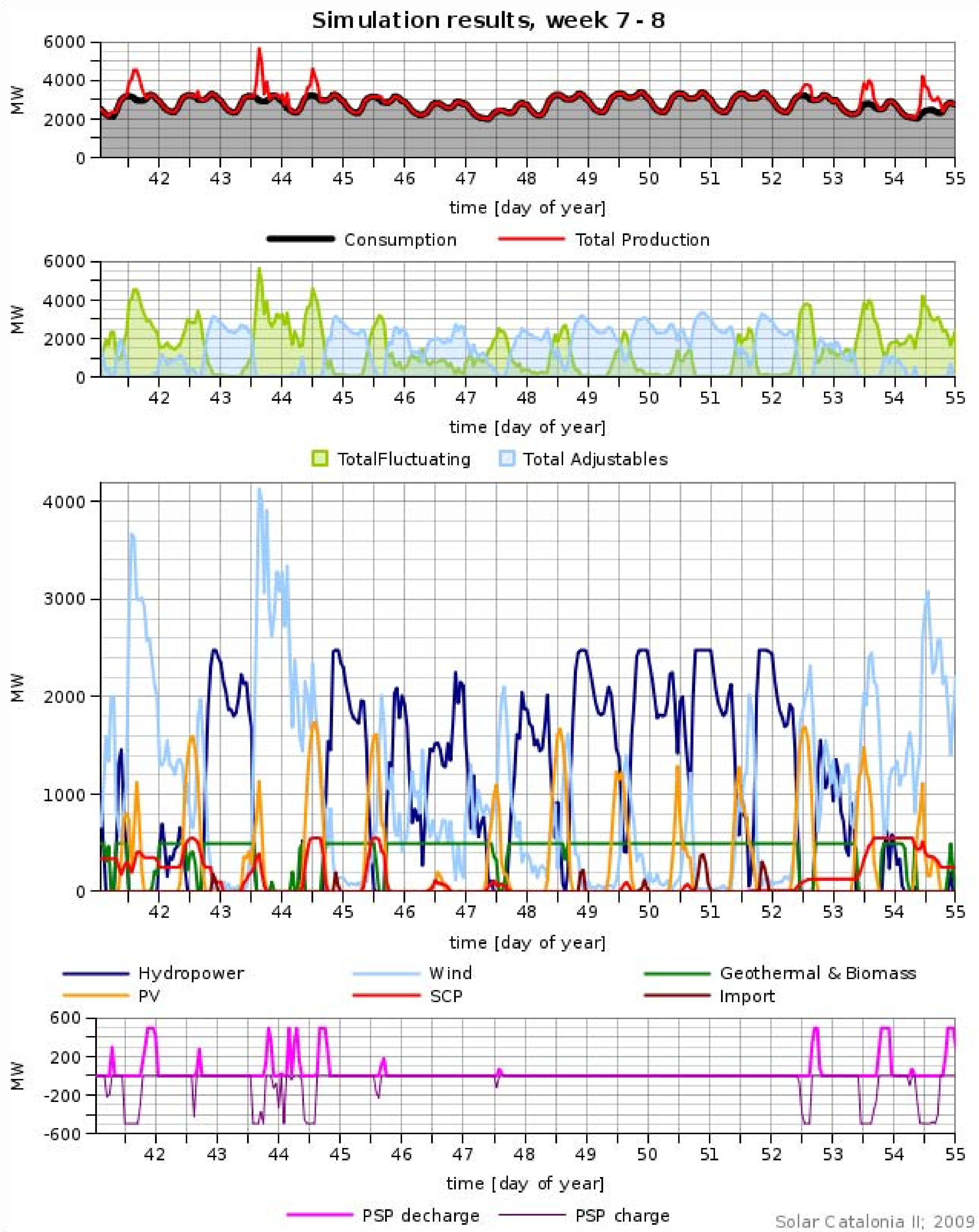


Solar Catalonia II; 2009

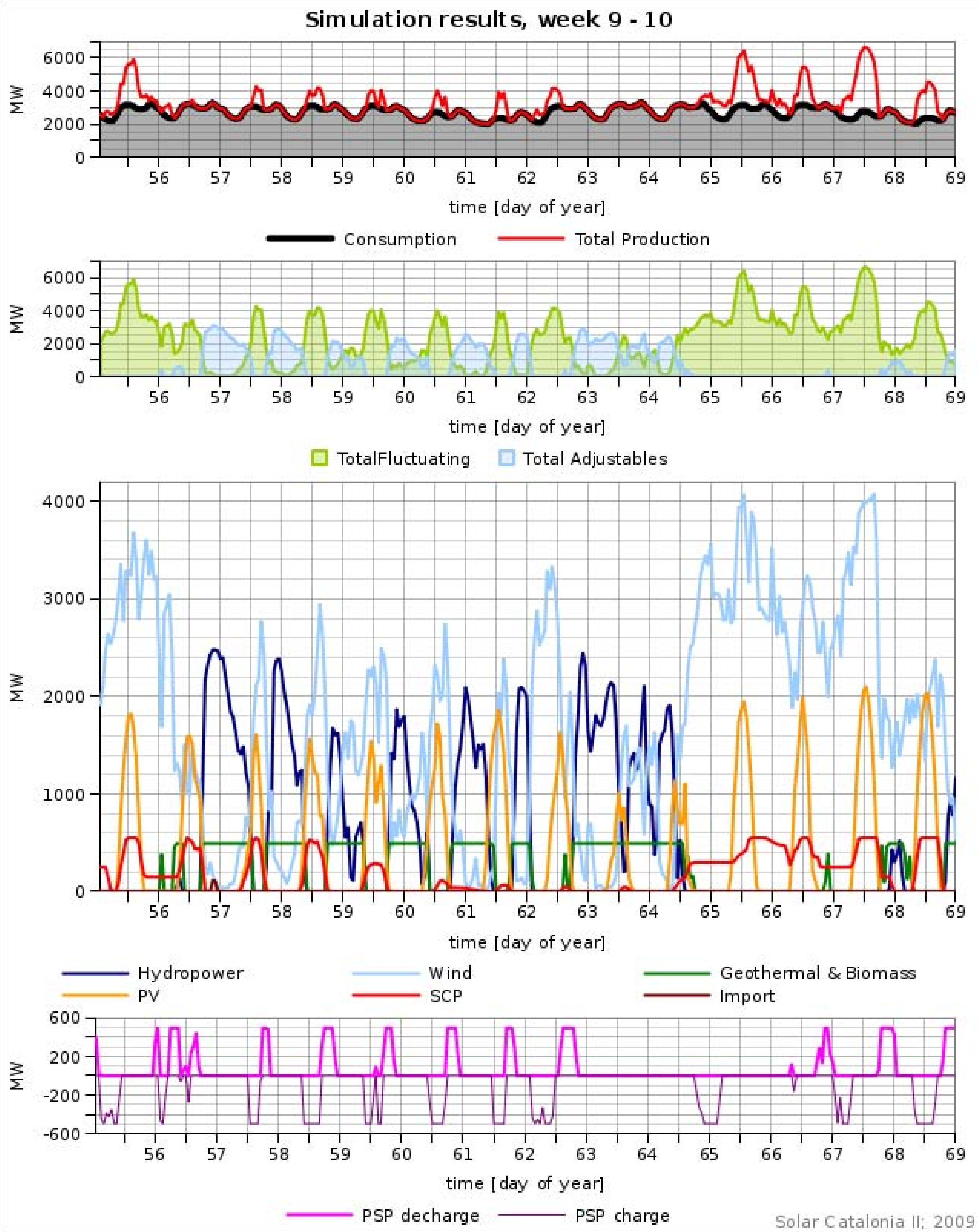


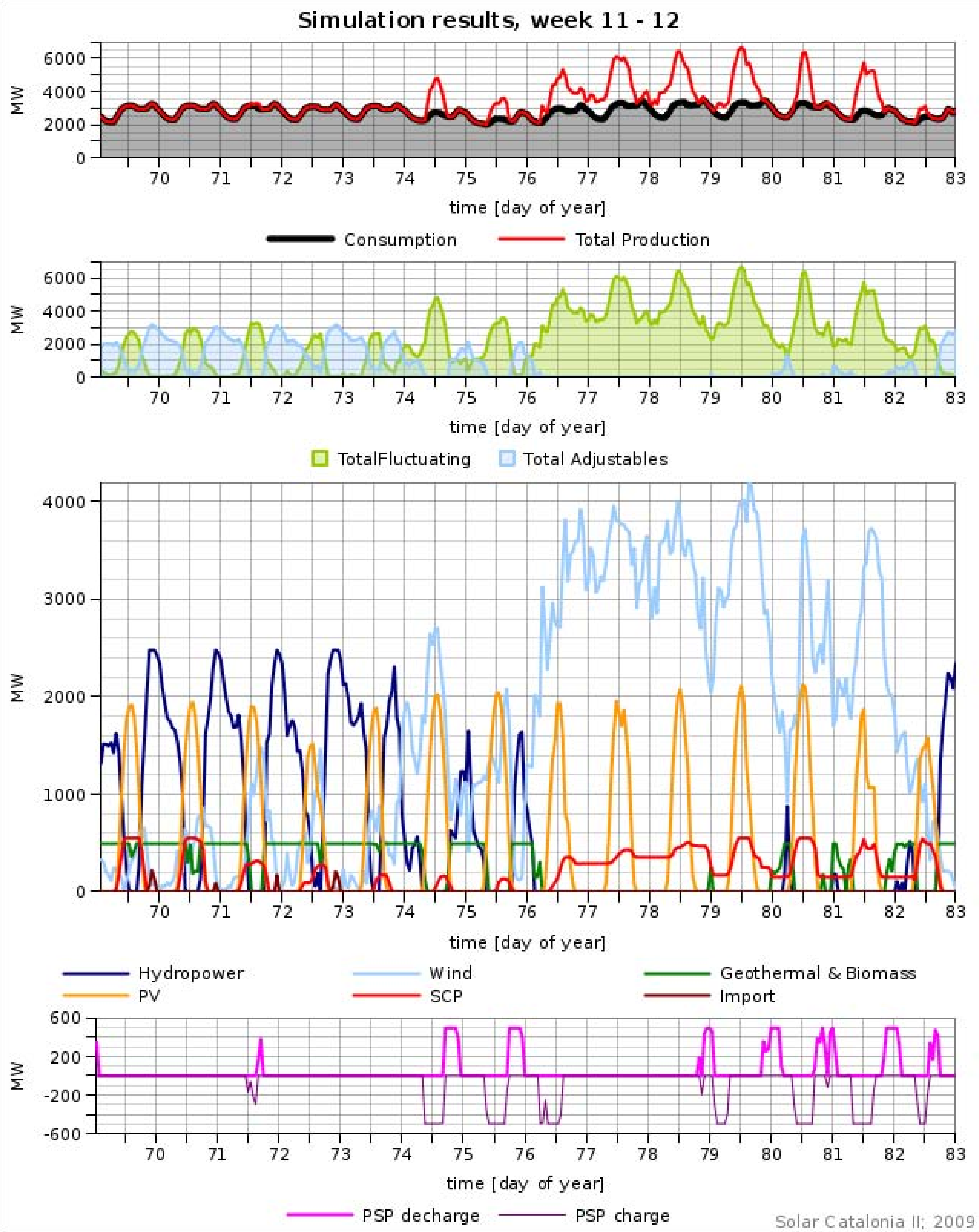
Simulation results, week 5 - 6

Solar Catalonia II; 2009

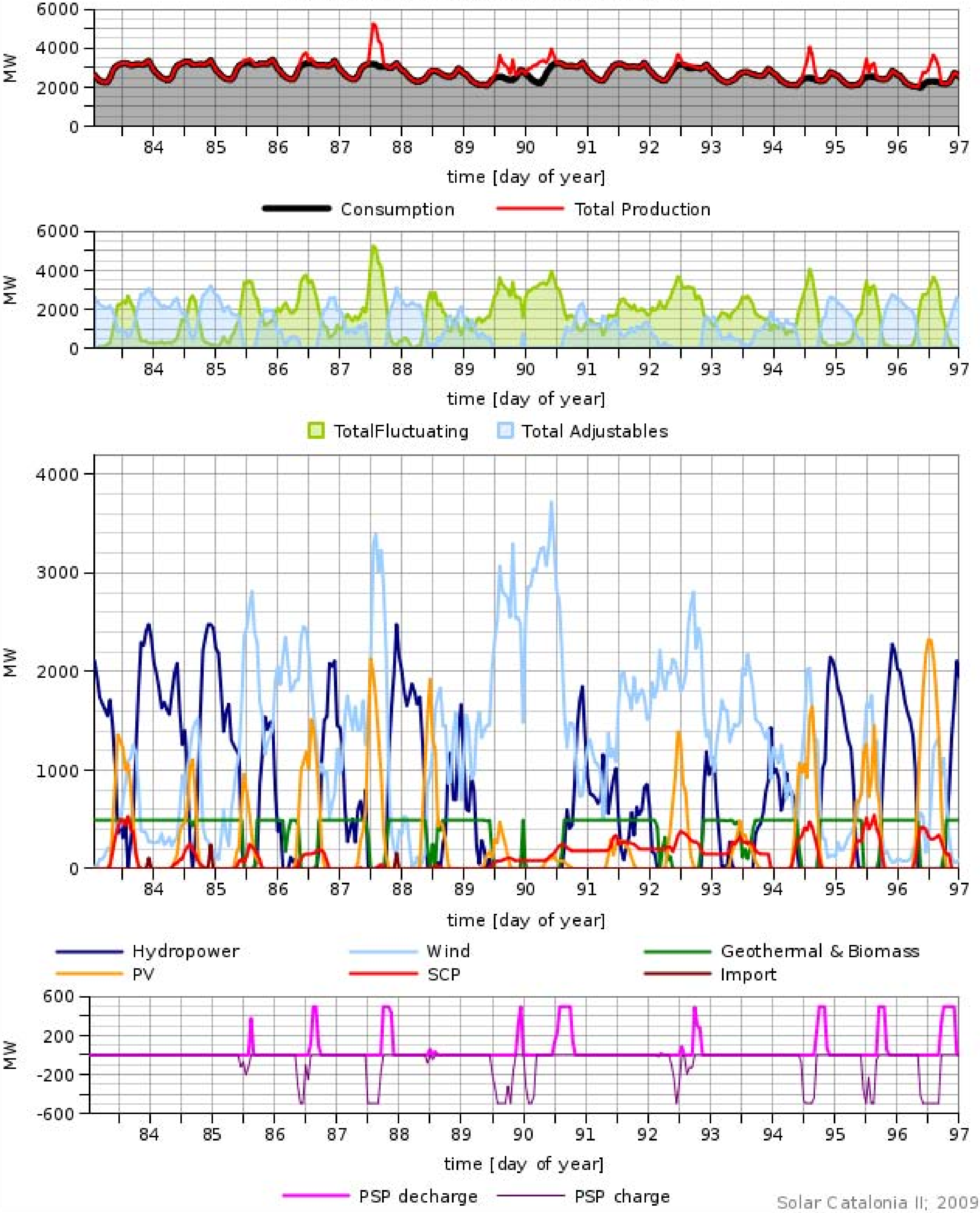


Solar Catalonia II; 2009

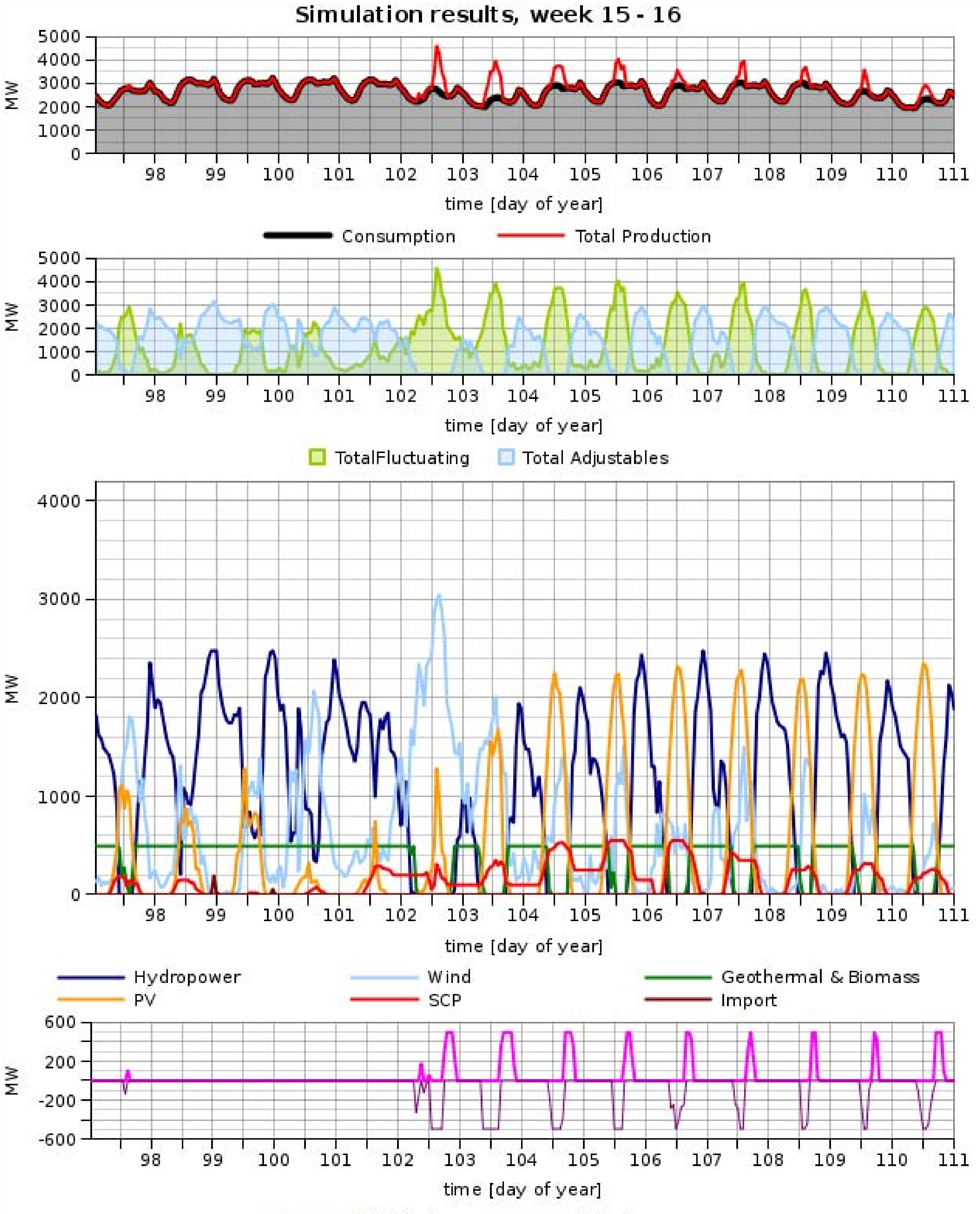

Simulation results, week 9 - 10
MW
6000
4000
2000
0
56
57
58
59
60
61
62
63
64
65
66
67
68
69
time [day of year]
Consumption
Total Production
MW
6000
4000
2000
0
time [day of year]
TotalFluctuating
Total Adjustables
MW
4000
3000
2000
1000
0
time [day of year]
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
MW
600
200
-200
-600
time [day of year]
PSP decharge
PSP charge
Solar Catalonia II; 2009


Simulation results, week 11 - 12
MW
6000
4000
2000
0
70
71
72
73
74
75
76
77
78
79
80
81
82
83
time [day of year]
Consumption
Total Production
MW
6000
4000
2000
0
time [day of year]
TotalFluctuating
Total Adjustables
MW
4000
3000
2000
1000
0
time [day of year]
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
MW
600
200
-200
-600
time [day of year]
PSP decharge
PSP charge
Solar Catalonia II; 2009

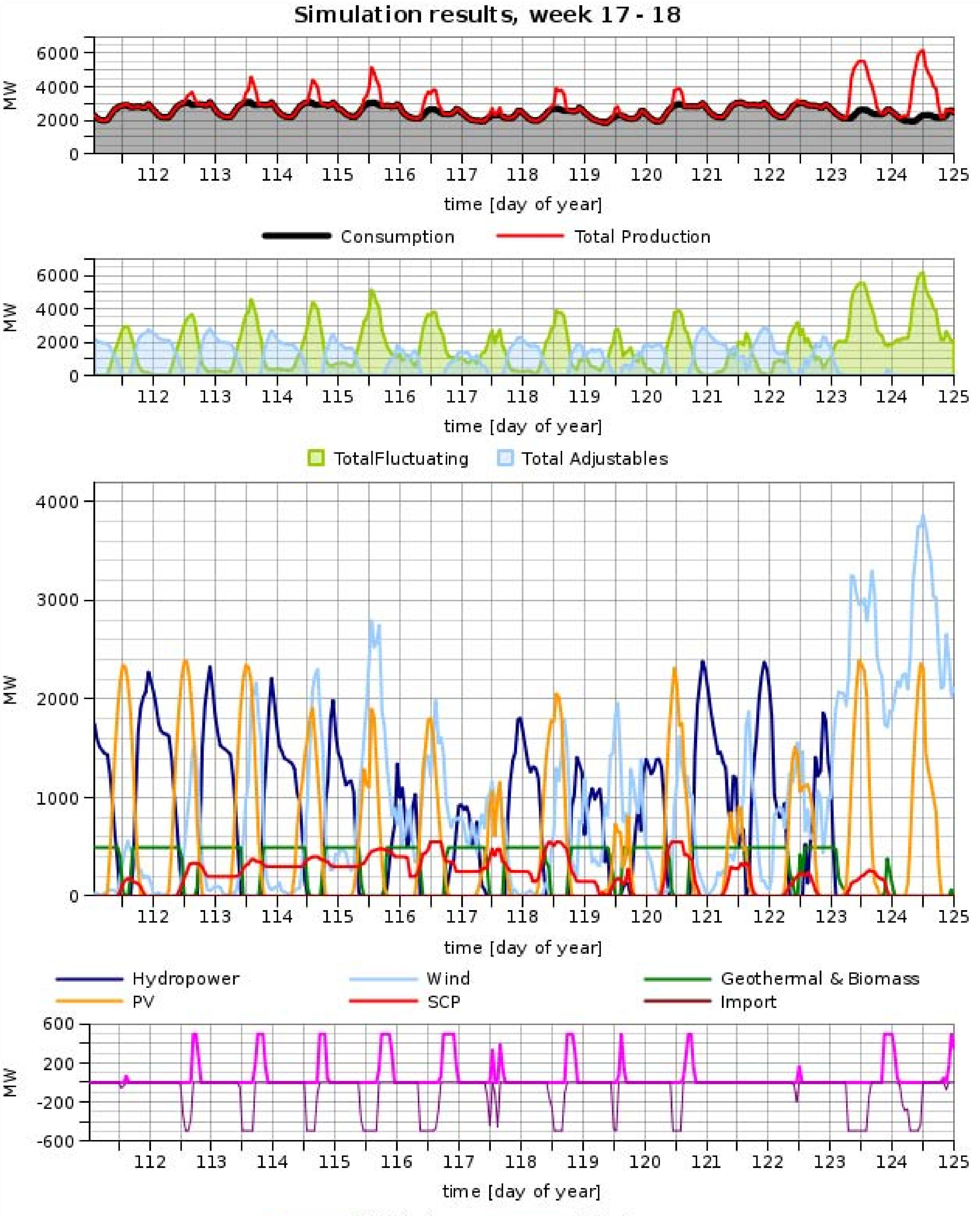
Simulation results, week 13 - 14



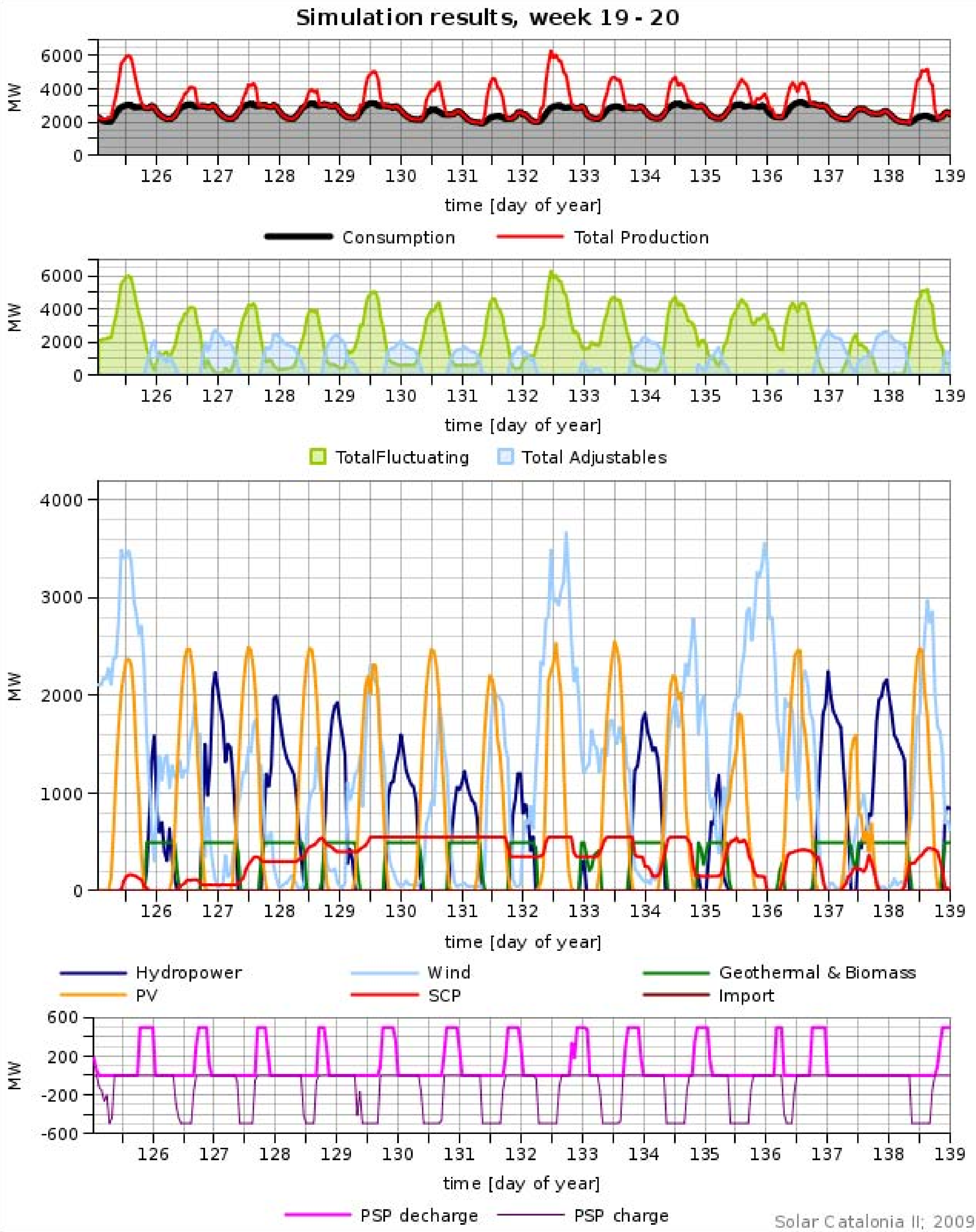
Solar Catalonia II; 2009



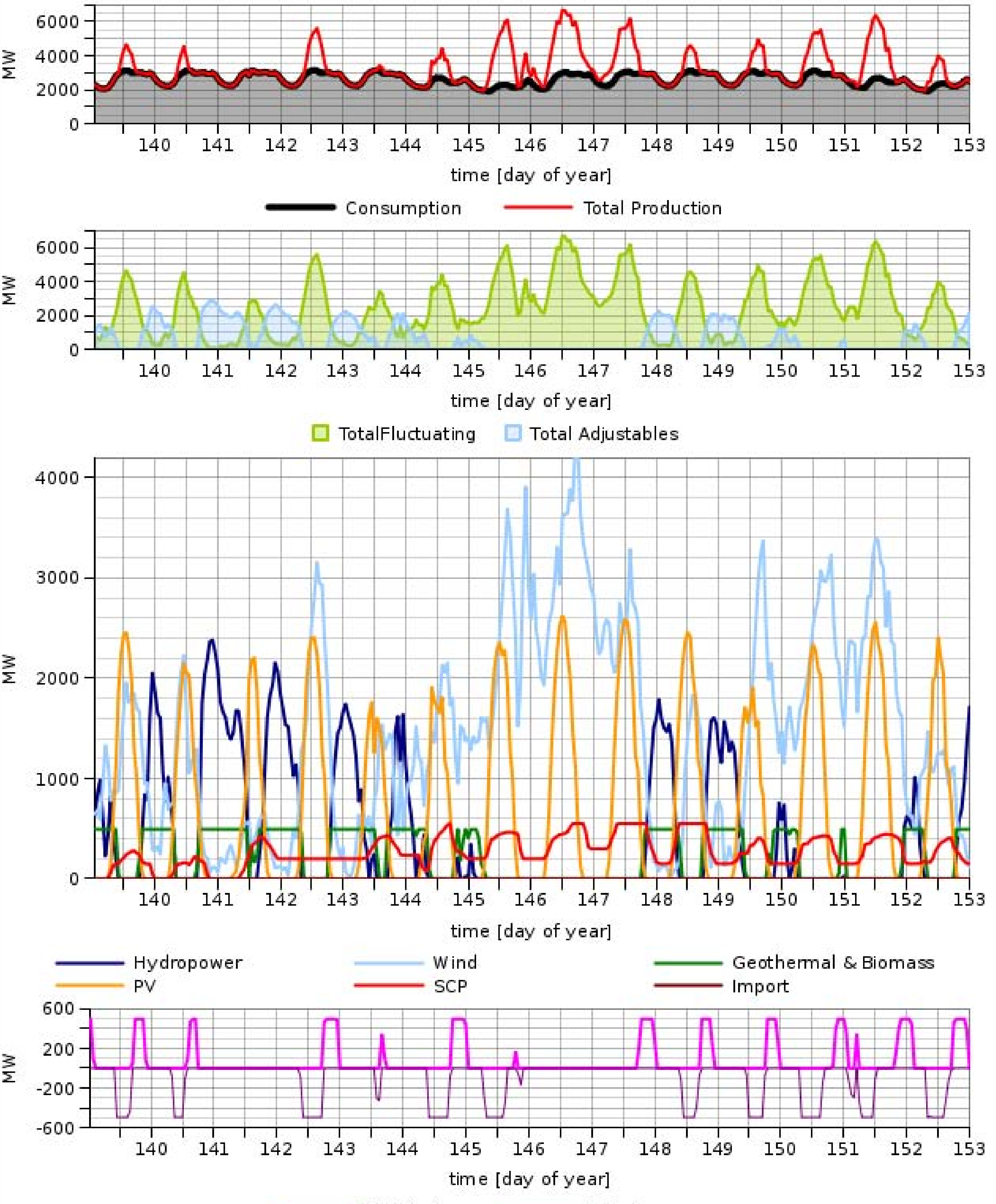
Solar Catalonia II; 2009



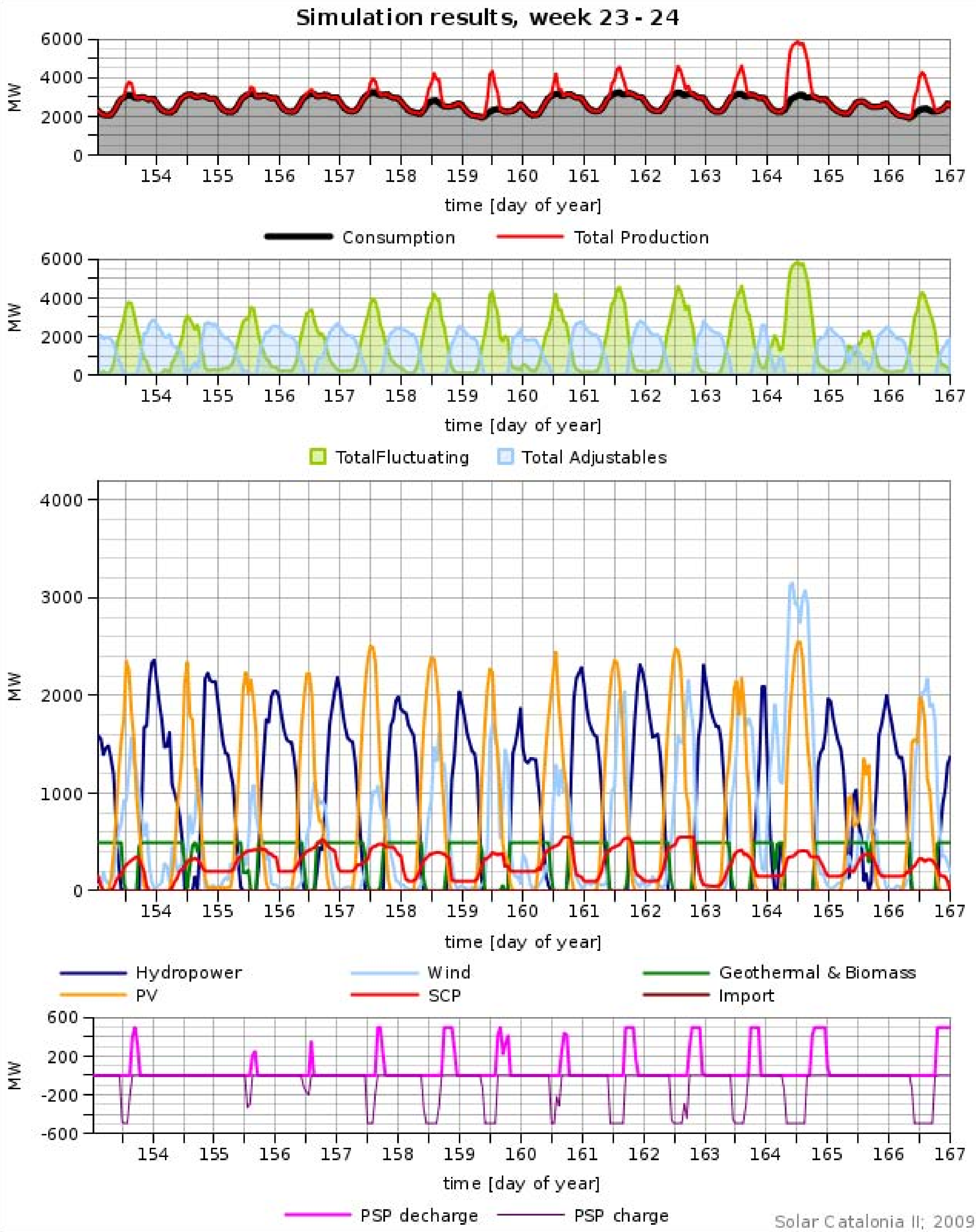
Solar Catalonia II; 2009

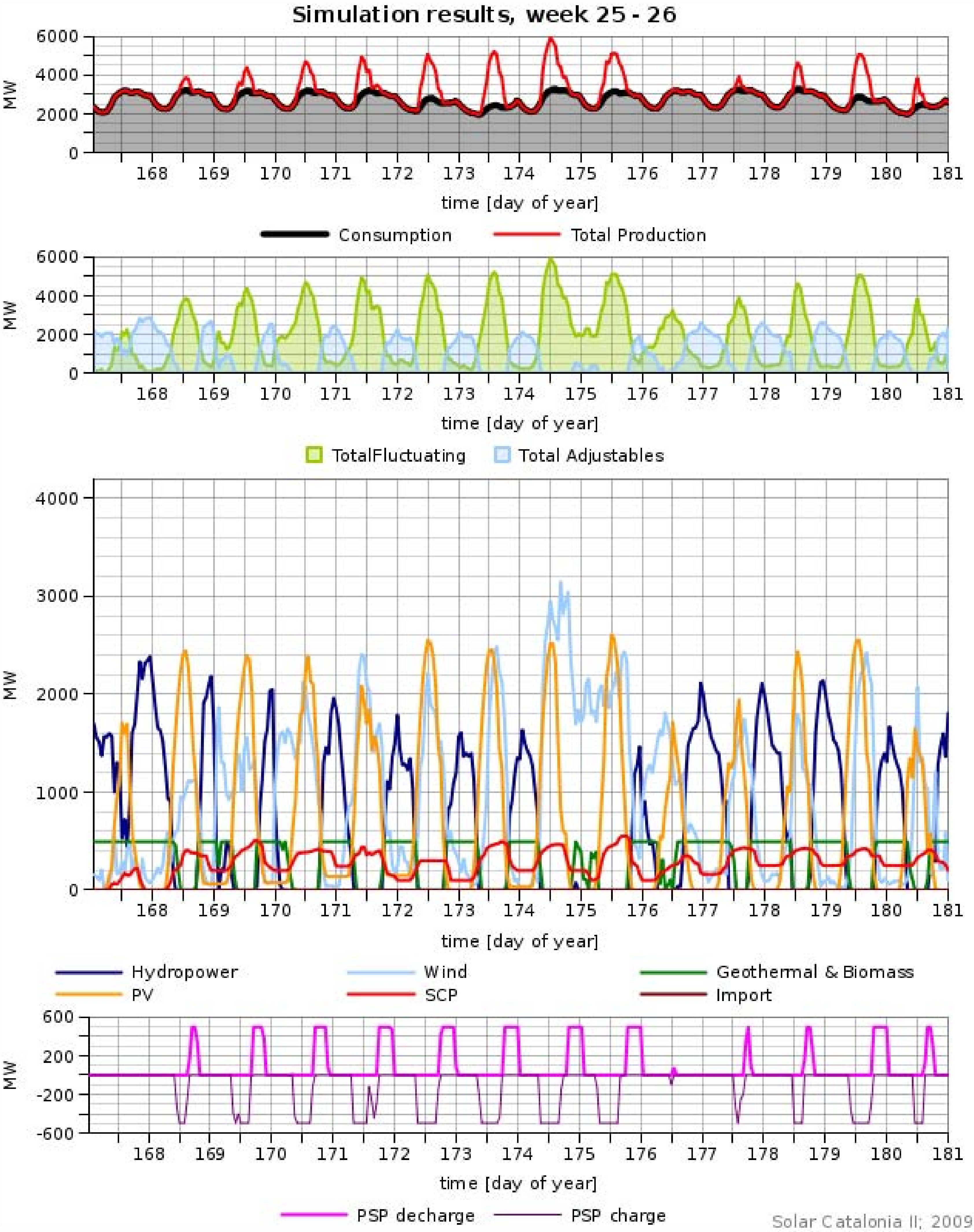

Simulation results, week 19 - 20
MW
6000
4000
2000
0
126
127
128
129
130
131
132
133
134
135
136
137
138
139
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

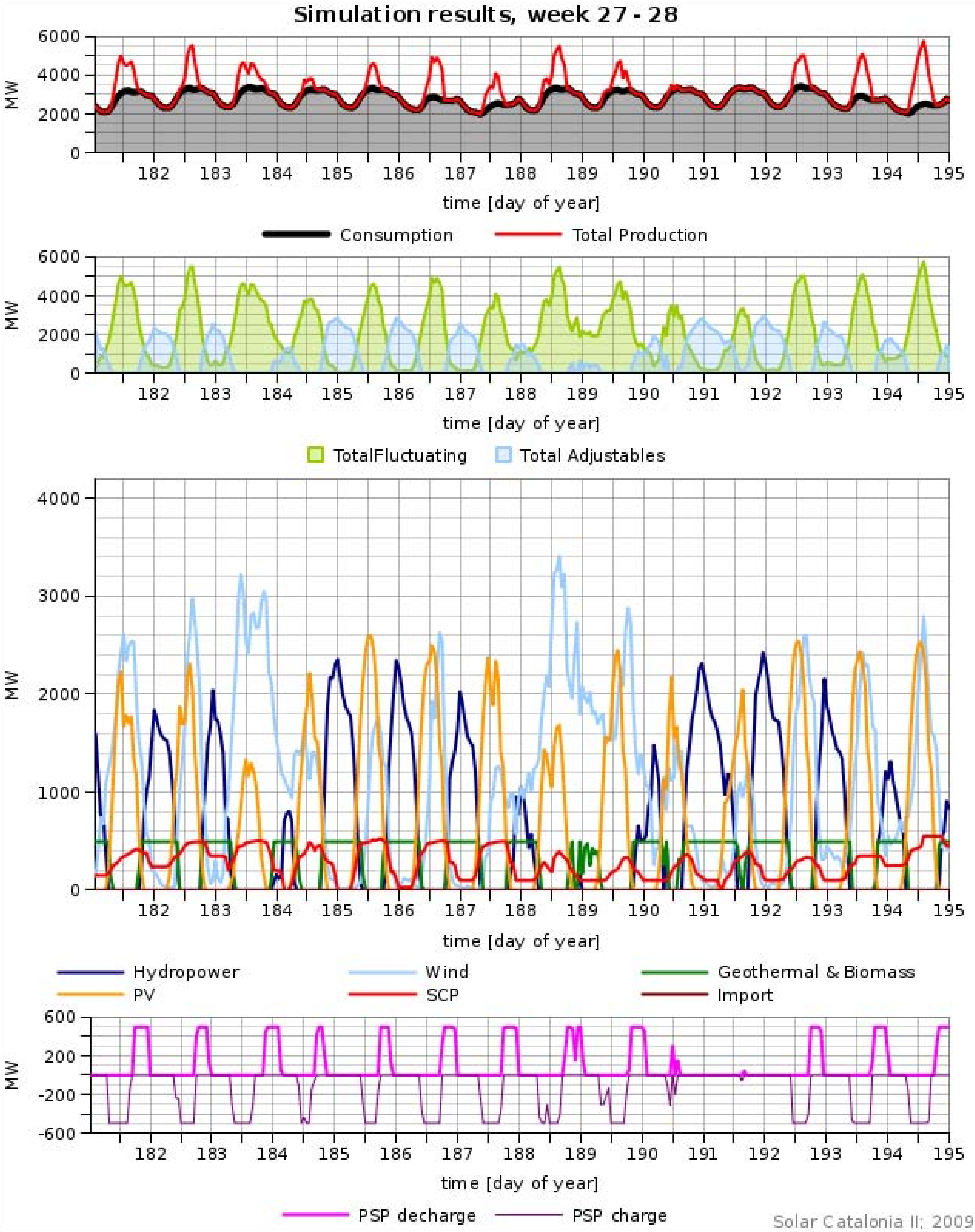
Simulation results, week 21 - 22



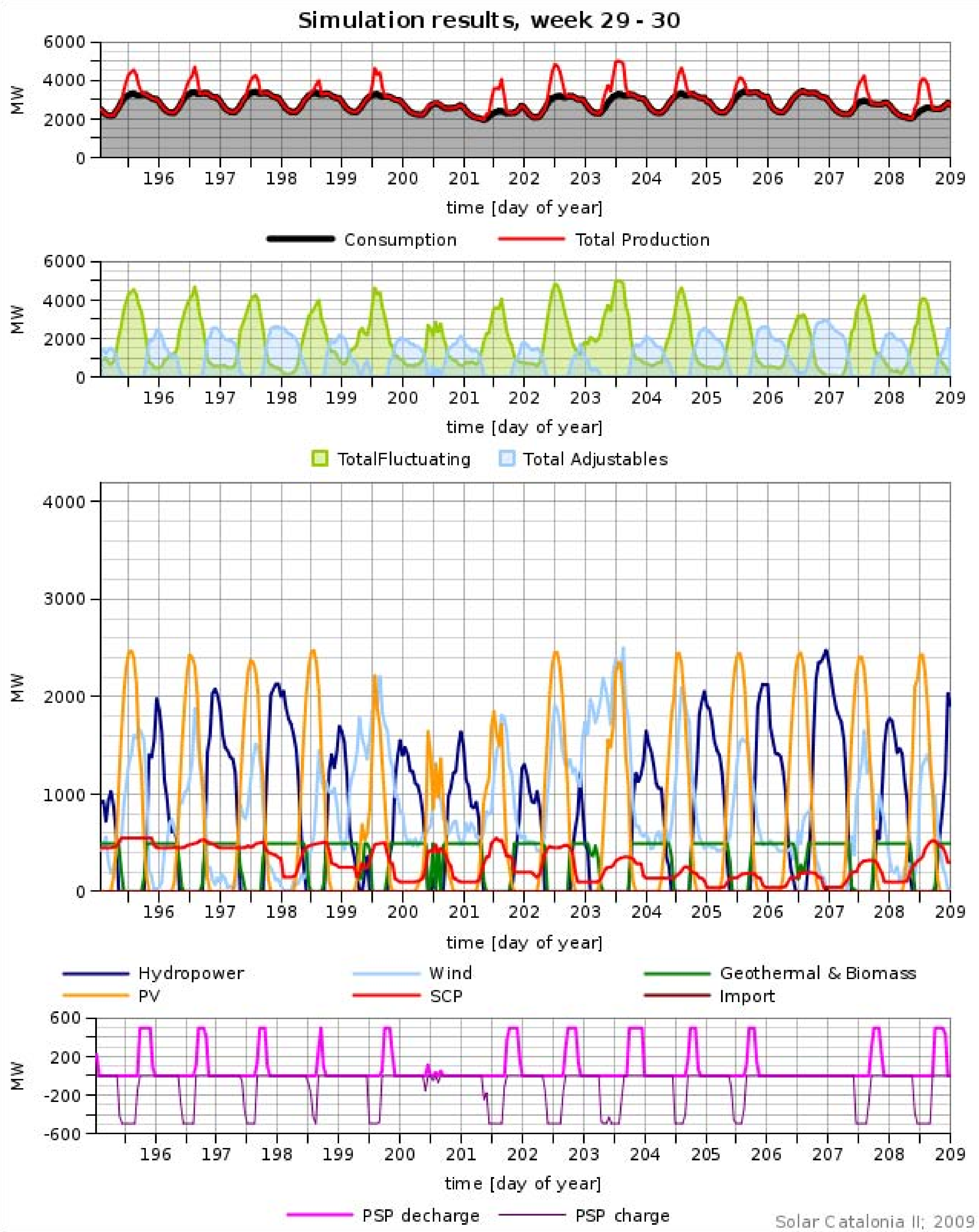
Solar Catalonia II; 2009

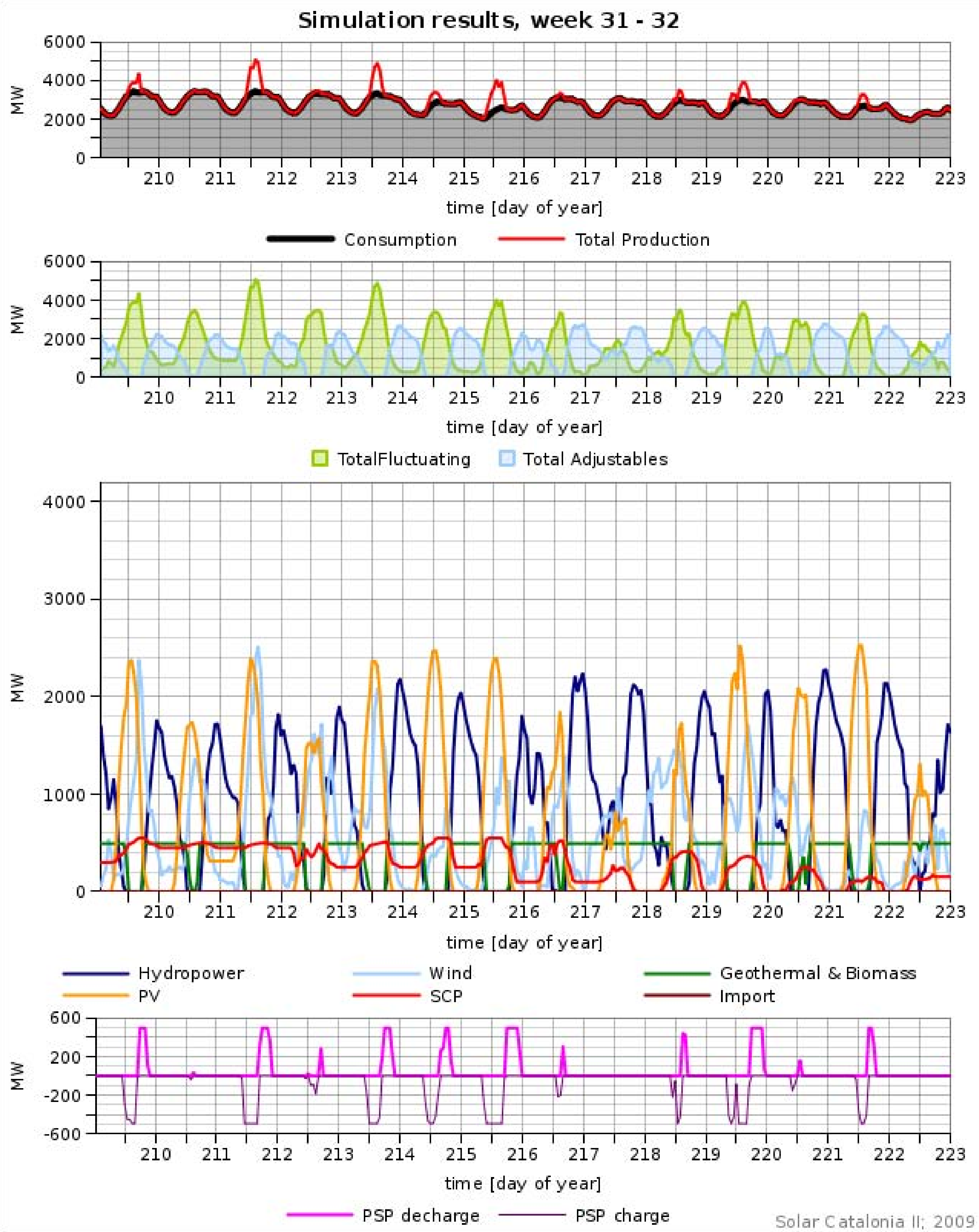

Simulation results, week 23 - 24
MW
6000
4000
2000
0
154
155
156
157
158
159
160
161
162
163
164
165
166
167
time [day of year]
Consumption
Total Production
MW
6000
4000
2000
0
time [day of year]
TotalFluctuating
Total Adjustables
MW
4000
3000
2000
1000
0
time [day of year]
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
MW
600
200
-200
-600
time [day of year]
PSP decharge
PSP charge
Solar Catalonia II; 2009

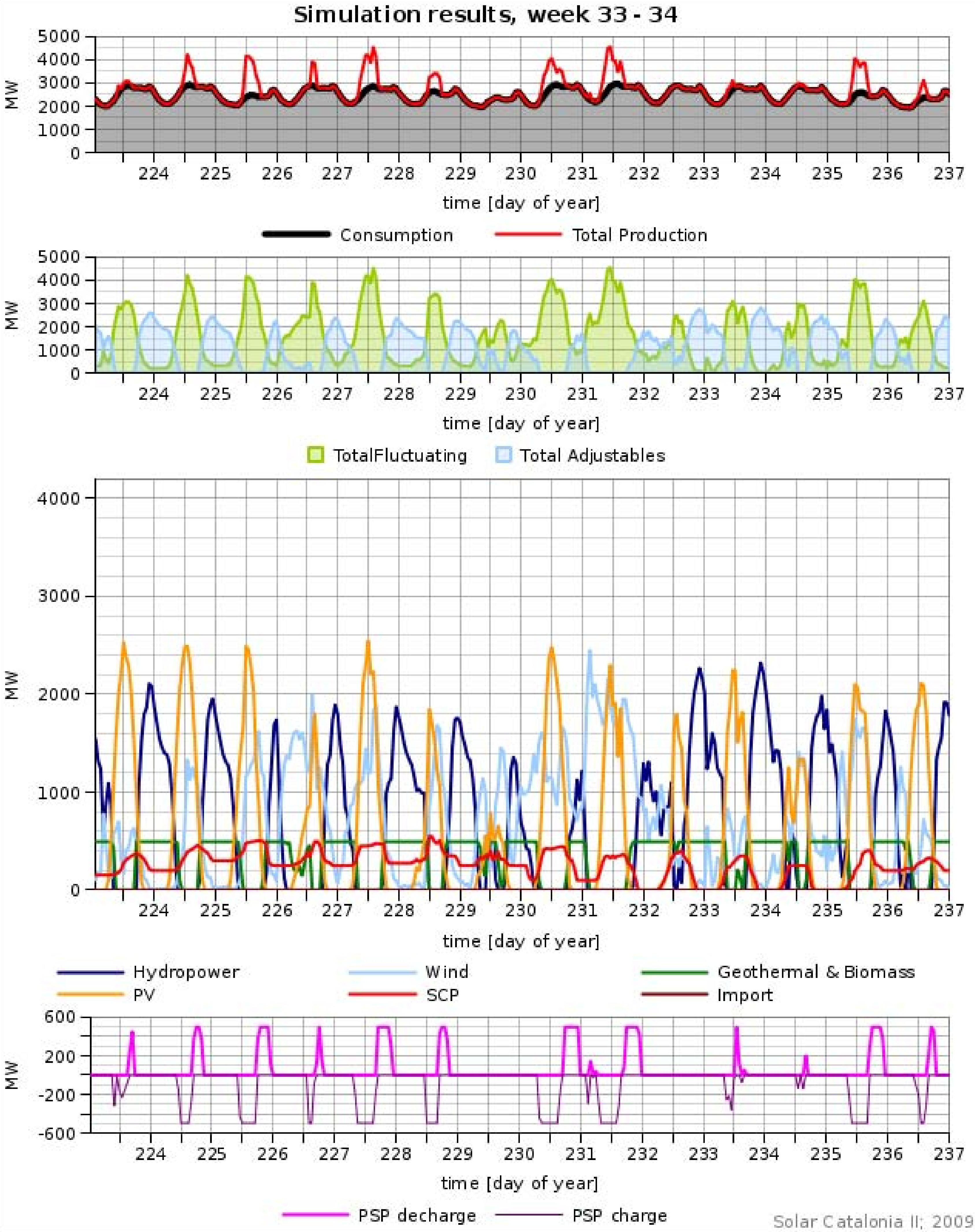

Simulation results, week 25 - 26
6000
4000
2000
0
MW
168
169
170
171
172
173
174
175
176
177
178
179
180
181
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
2000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

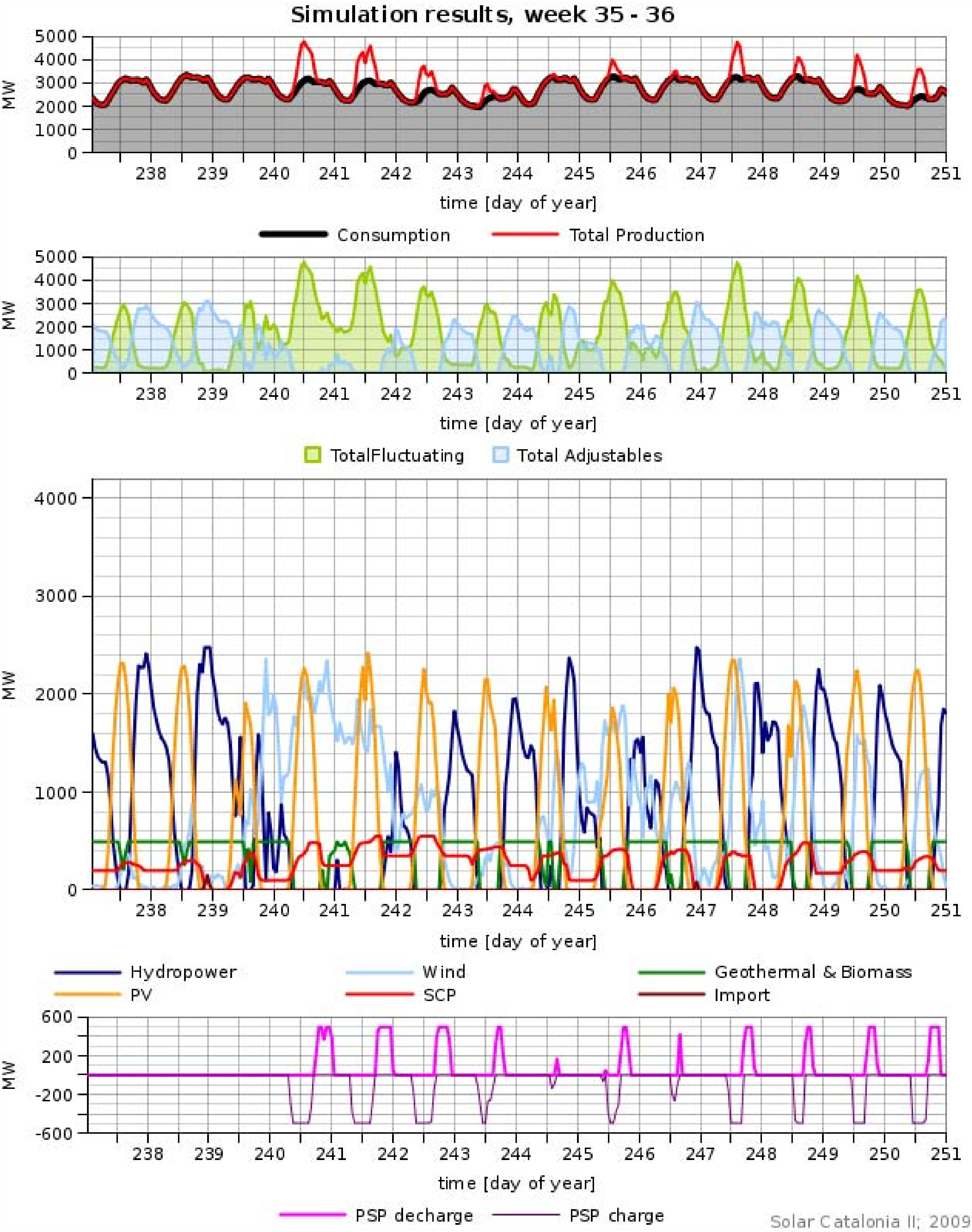


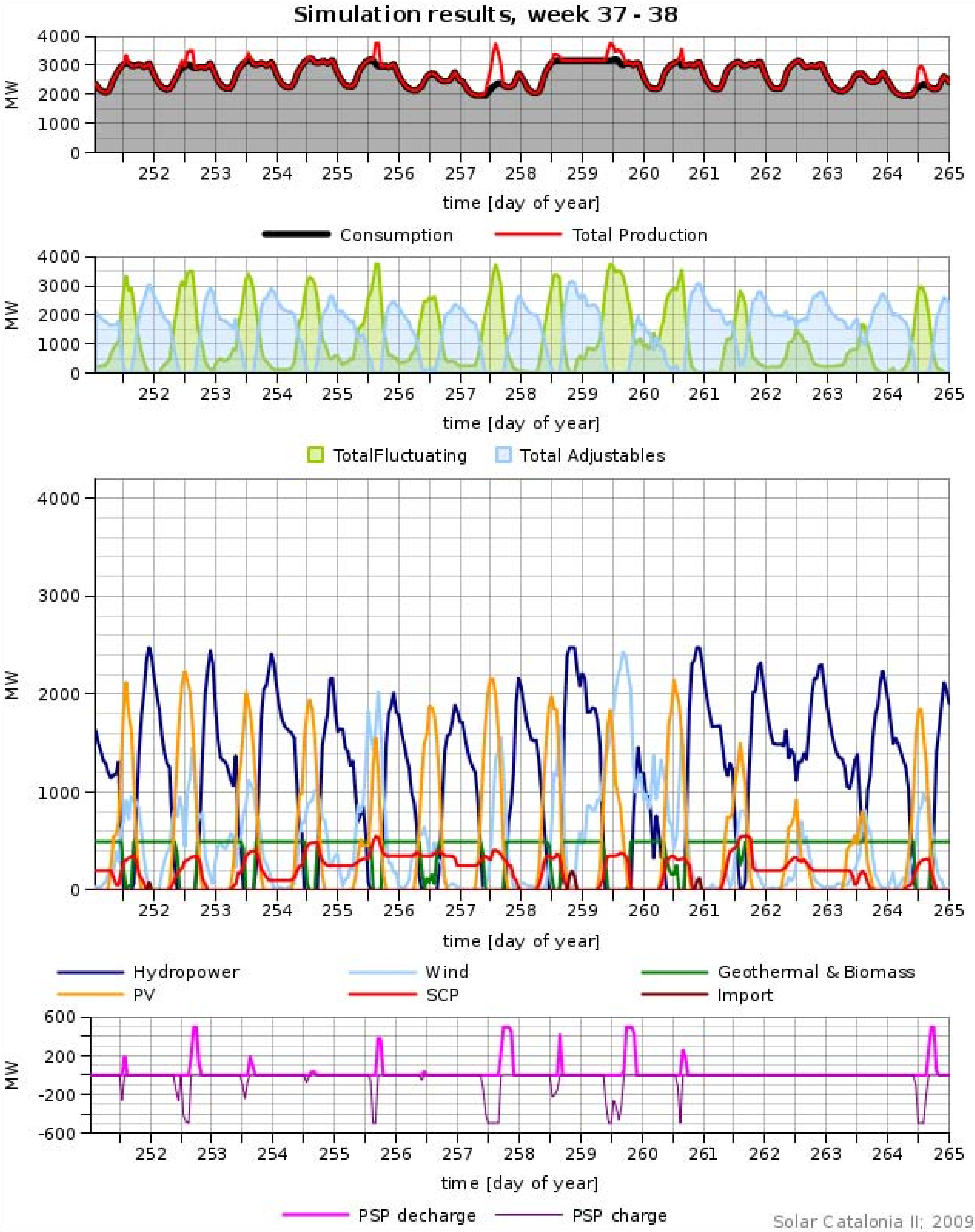
Solar Catalonia II; 2009


Simulation results, week 29 - 30
MW
6000
4000
2000
0
196
197
198
199
200
201
202
203
204
205
206
207
208
209
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
2000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009


Simulation results, week 31 - 32
6000
4000
2000
0
MW
210
211
212
213
214
215
216
217
218
219
220
221
222
223
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
2000
1000
0
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

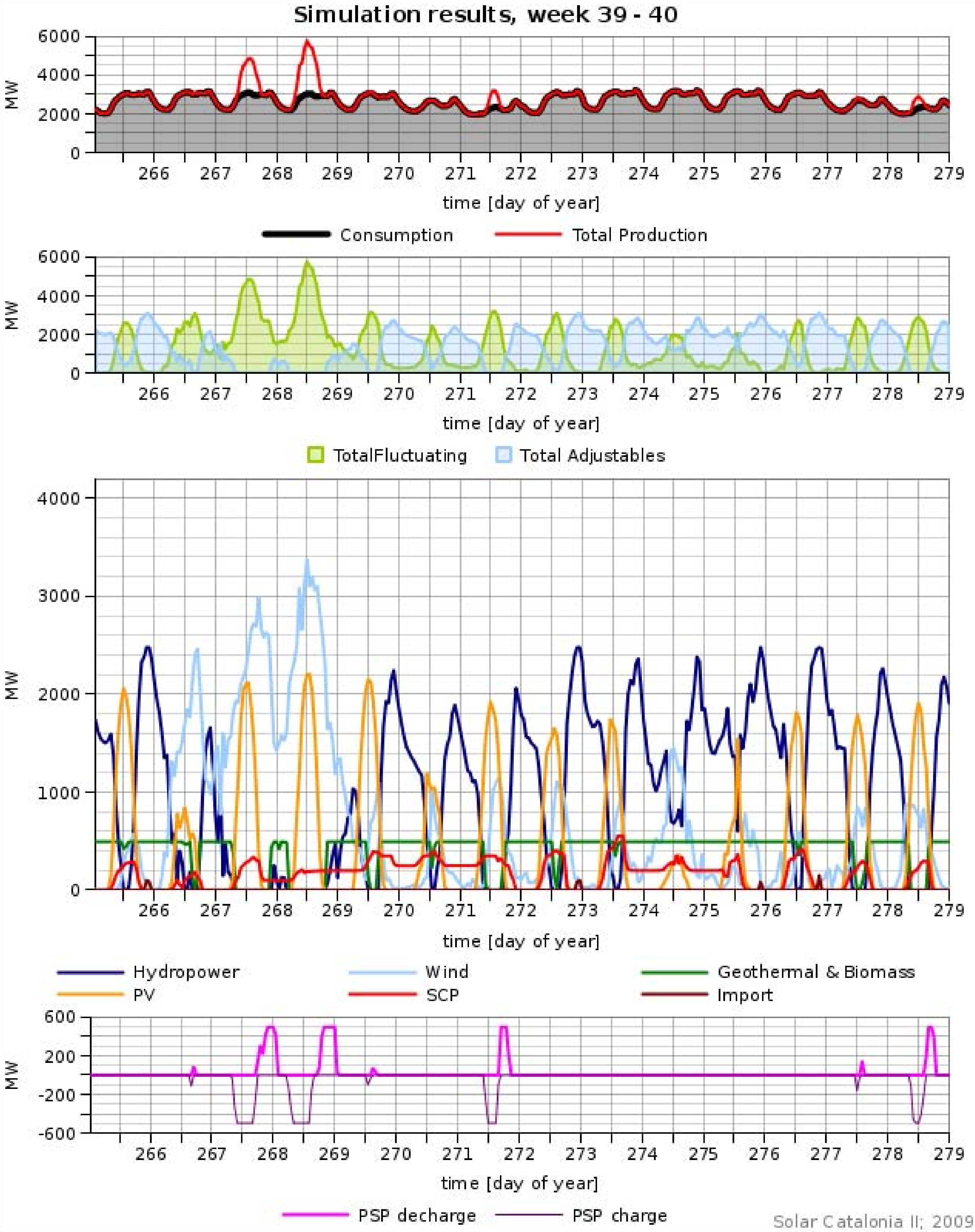

Simulation results, week 33 - 34
MW
5000
4000
3000
2000
1000
0
224
225
226
227
228
229
230
231
232
233
234
235
236
237
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
2000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

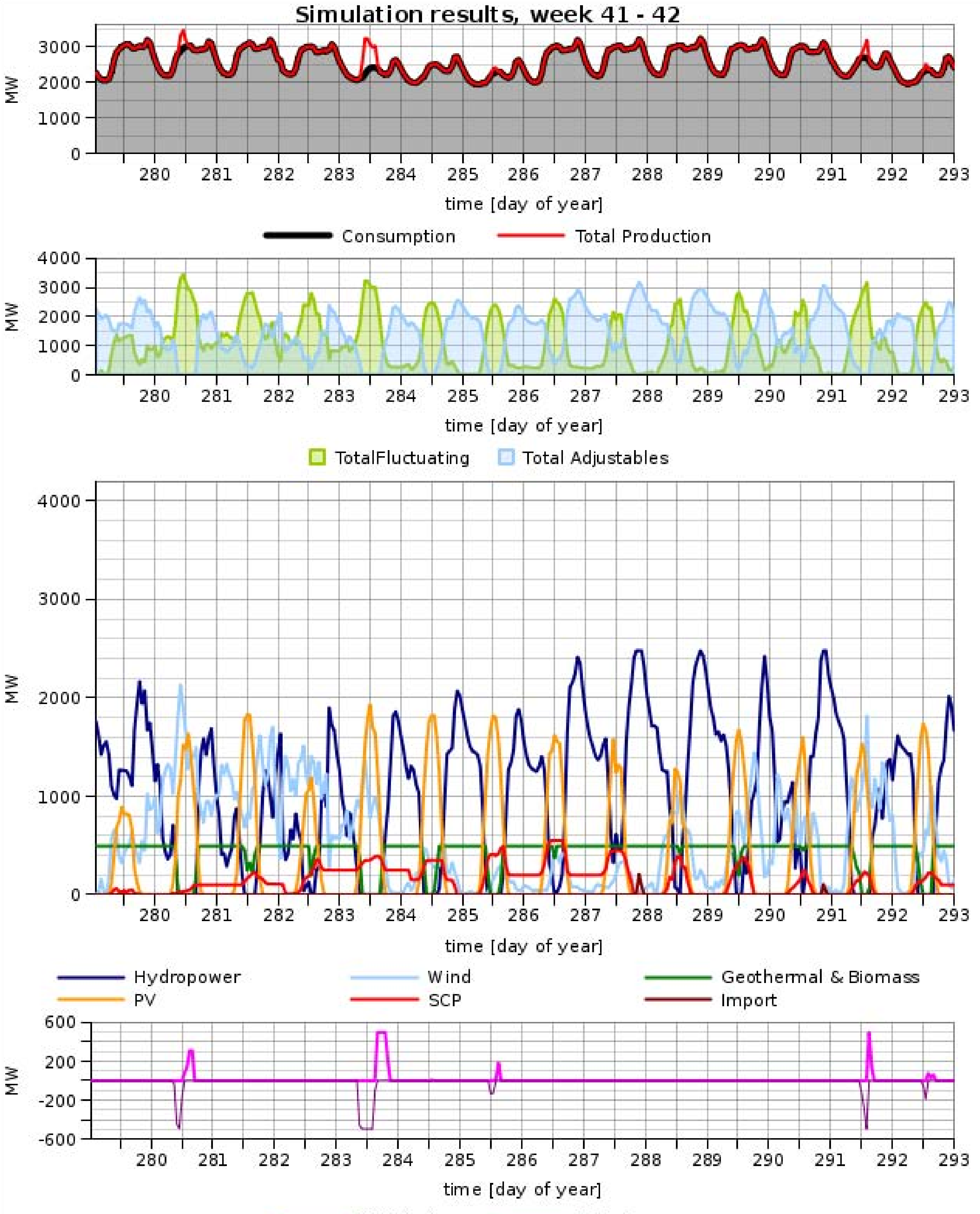

Simulation results, week 35 - 36
5000
4000
3000
2000
1000
0
MW
238
239
240
241
242
243
244
245
246
247
248
249
250
251
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
2000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009



Simulation results, week 37 - 38

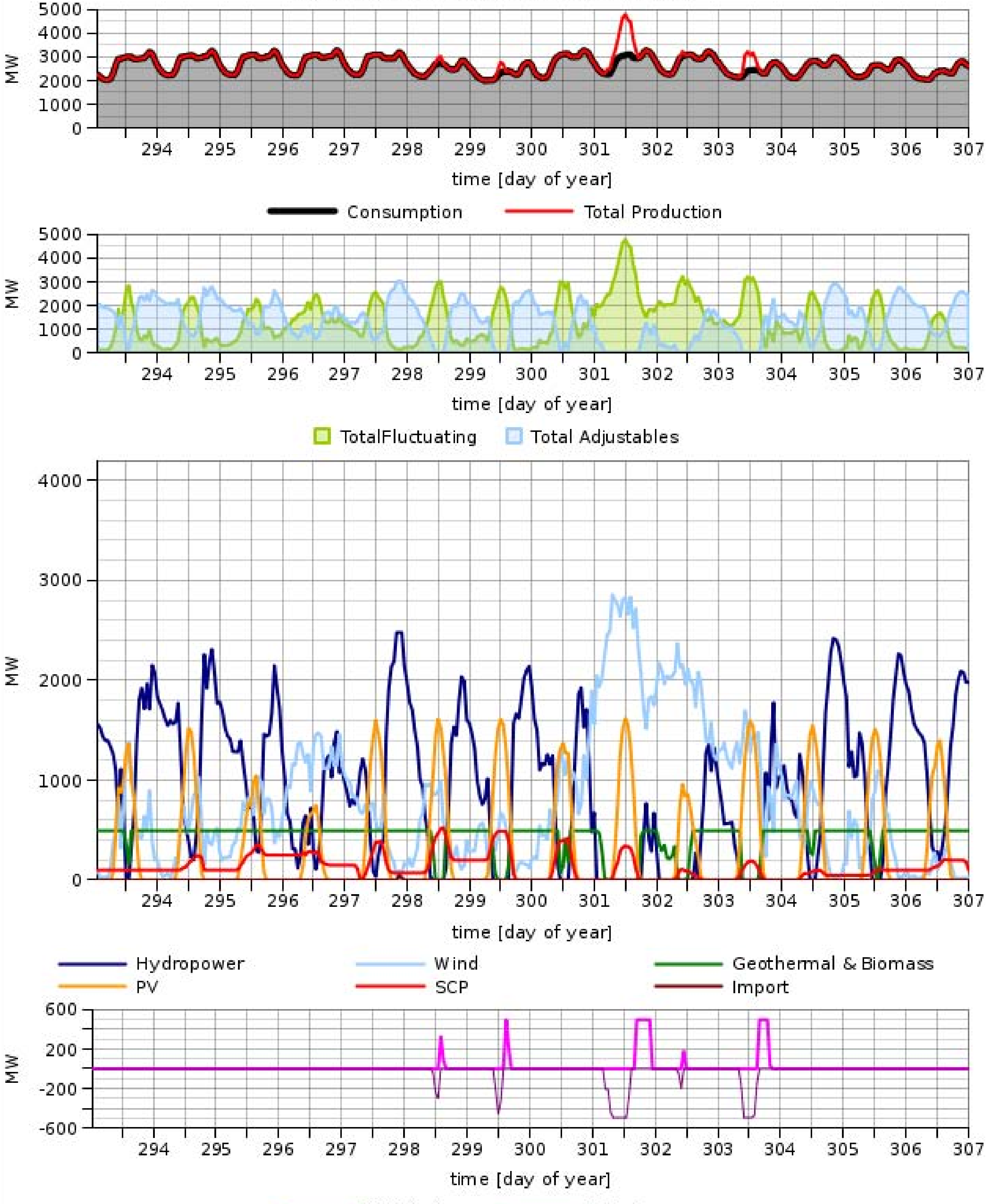
Solar Catalonia II; 2009


Simulation results, week 39 - 40
MW
6000
4000
2000
0
266
267
268
269
270
271
272
273
274
275
276
277
278
279
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
4000
3000
1000
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

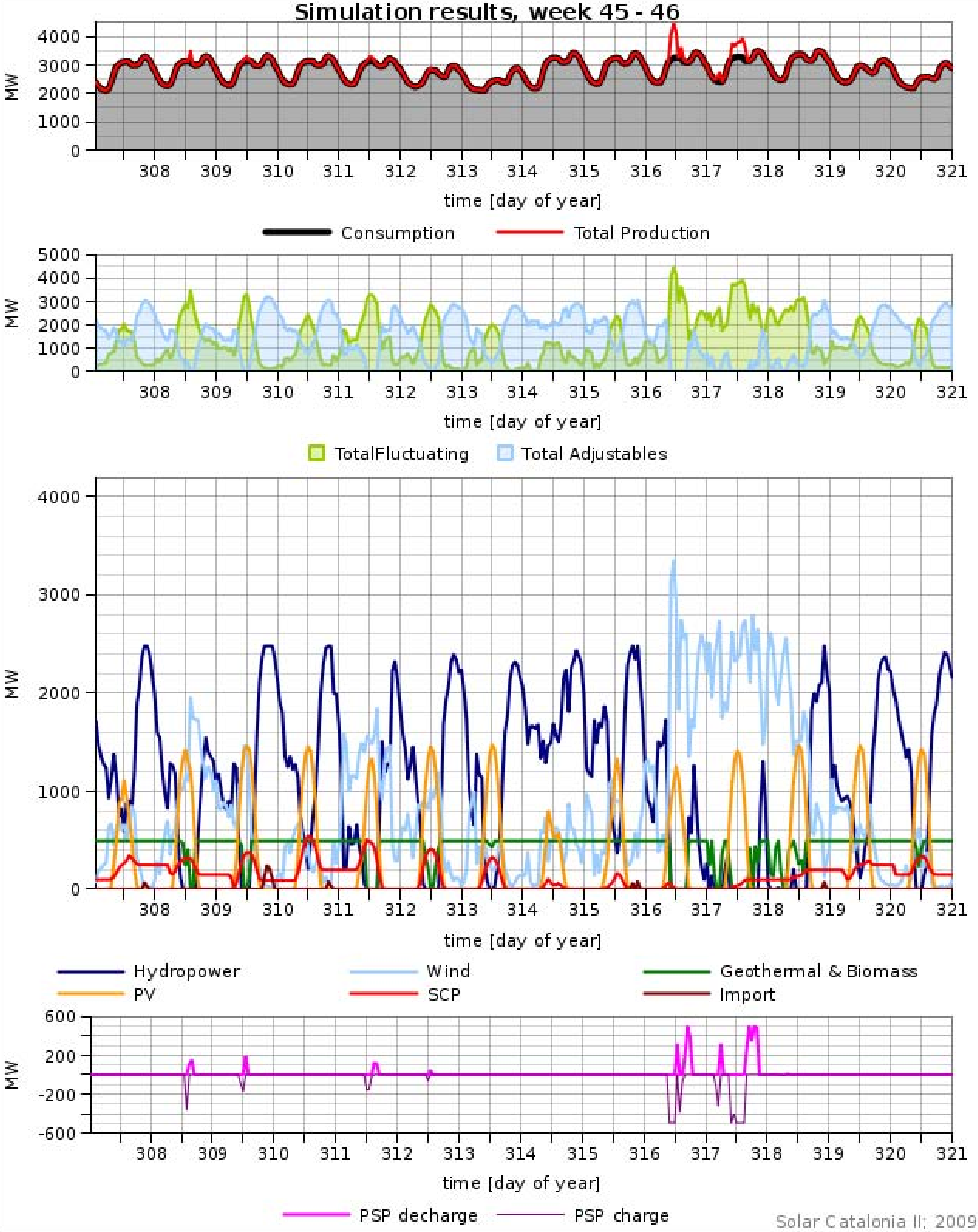


Solar Catalonia II; 2009

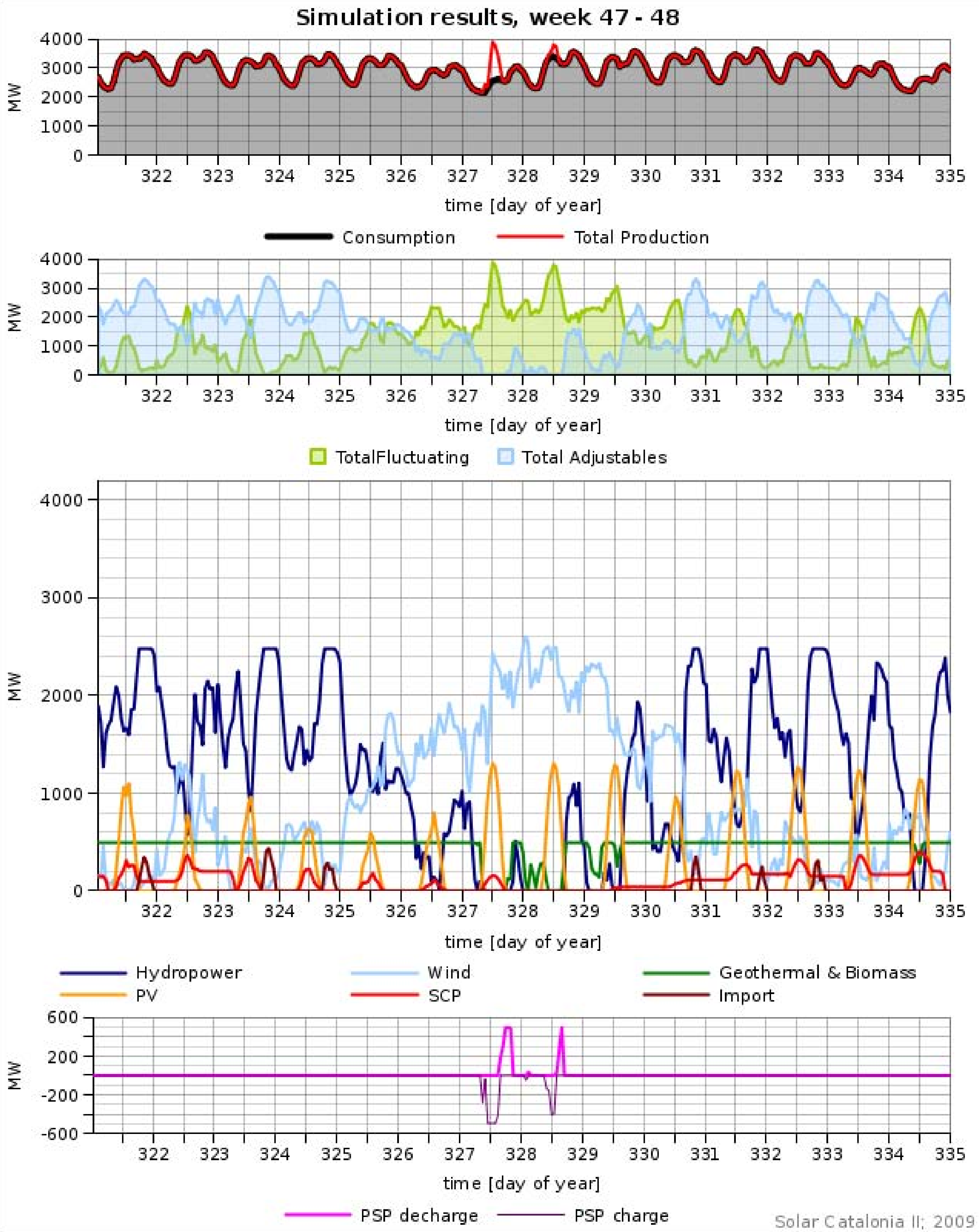
Simulation results, week 43 - 44

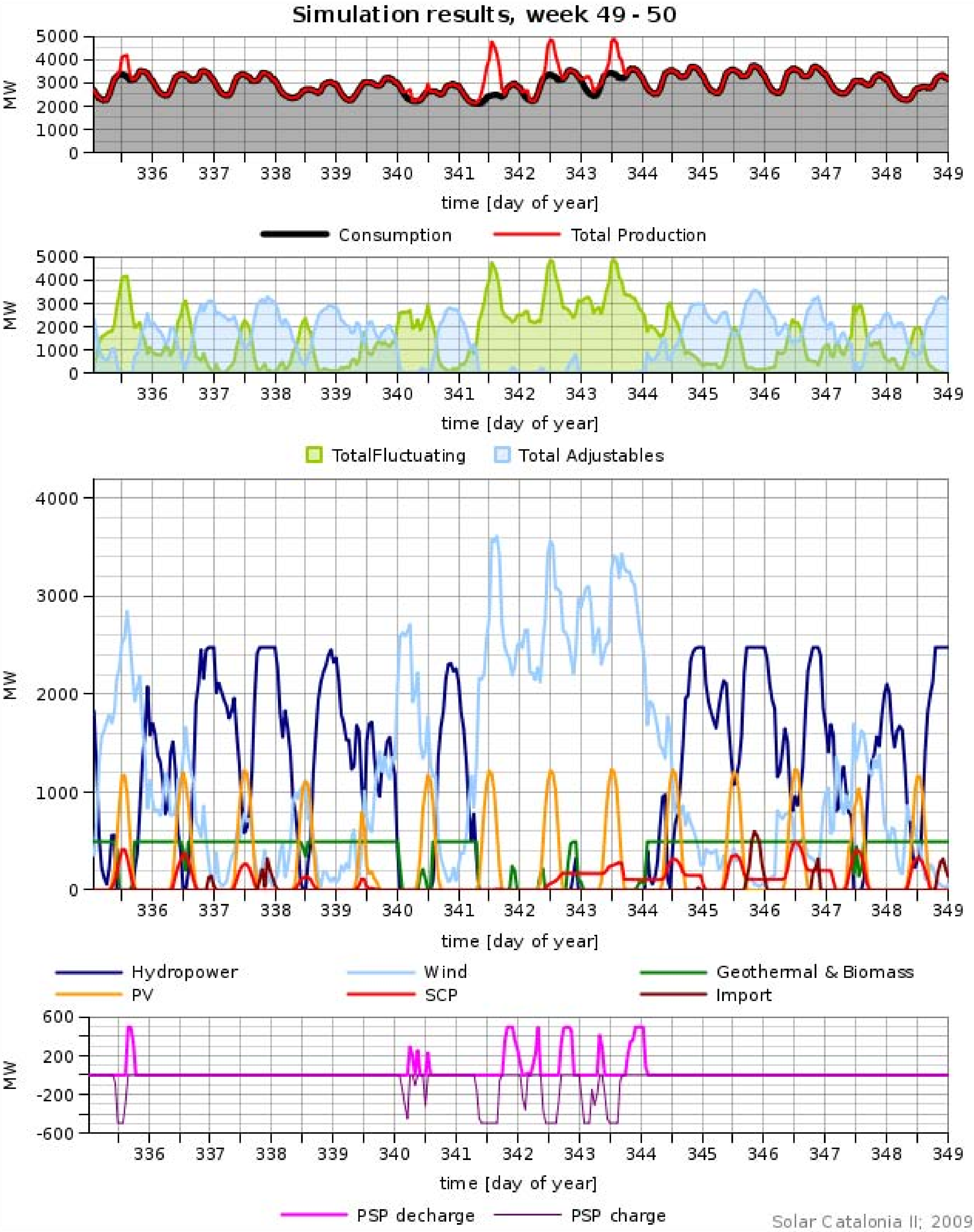


Solar Catalonia II; 2009


Simulation results, week 45 - 46

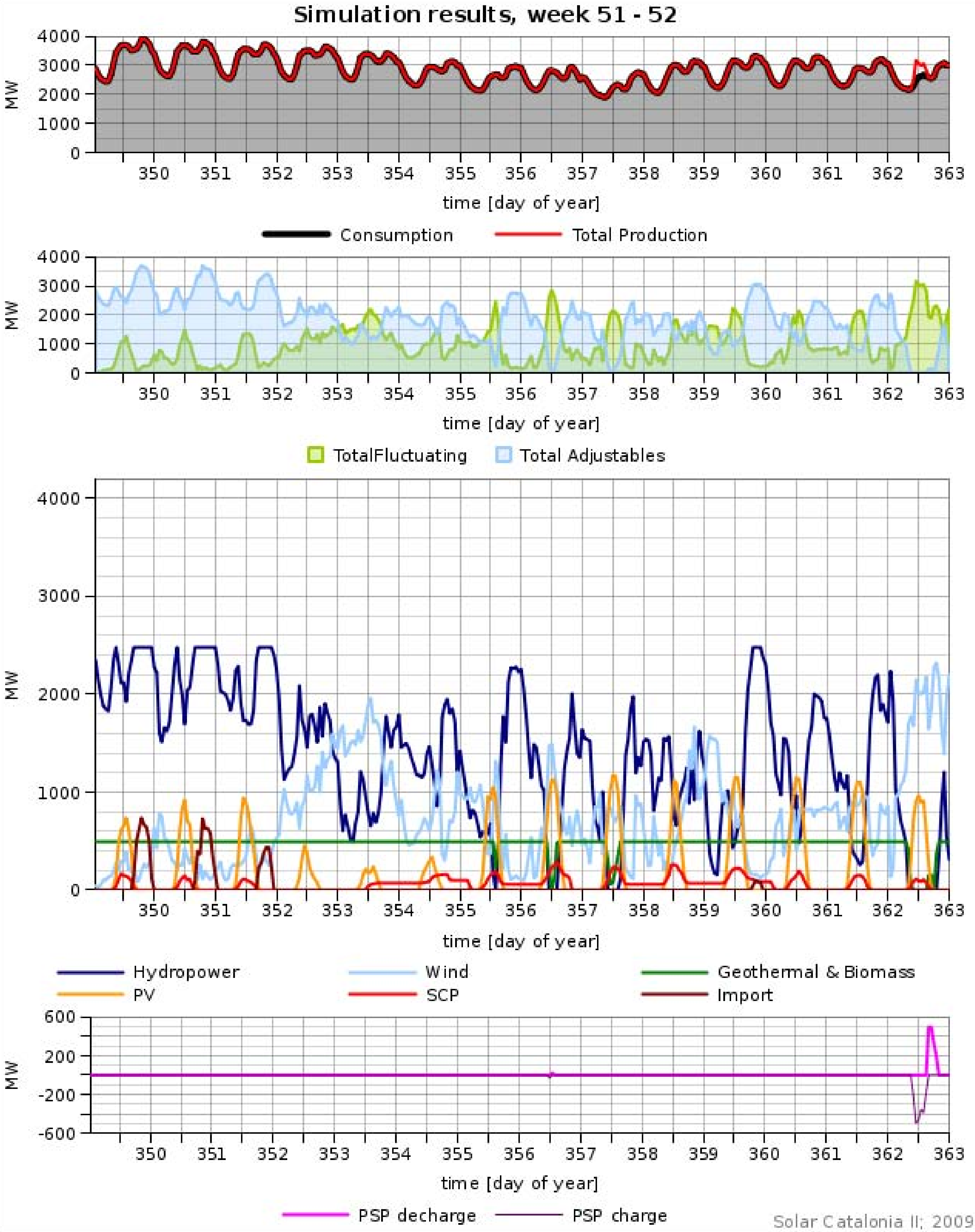
Solar Catalonia II; 2009


Simulation results, week 47 - 48
4000
3000
2000
1000
0
MW
322
323
324
325
326
327
328
329
330
331
332
333
334
335
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009



Simulation results, week 49 - 50

Solar Catalonia II; 2009


Simulation results, week 51 - 52
MW
4000
3000
2000
1000
0
350
351
352
353
354
355
356
357
358
359
360
361
362
363
time [day of year]
Consumption
Total Production
TotalFluctuating
Total Adjustables
Hydropower
Wind
Geothermal & Biomass
PV
SCP
Import
600
200
-200
-600
PSP decharge
PSP charge
Solar Catalonia II; 2009

Hi col·laboren

Obra Social "la Caixa"

MEDI AMBIENT I HABITATGE

Generalitat de Catalunya
Departament
de Medi Ambient i Habitatge