The Energy System in Aragón Facing the Future

Master's Thesis within the Sustainable Energy Systems programme

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Division of Energy Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2012

Master of Science Thesis T2012-370

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ABSTRACT

The aim of this Master Thesis is to study the development of the energy system in Aragón and analyze some options for its future development. A systems approach is applied.

The report is divided in two parts. The first part studies in the historical evolution of the energy system, analyzing the electrical system in detail. The second part focuses in energy modeling.

The first step is a literature review to find historical data about the energy system, and more in detail about the electrical system. The second part includes three different models: logistic curves of the electrical system, energy balance flow diagram and Long range Energy Alternatives Planning system (LEAP). Four scenarios are built using LEAP: the business as usual (BAU), coal priority (COAL), renewable electricity (REN) and electric cars (ELECAR).

During the development of the project an important quantity of data about the energy system in Aragón has been found. However, when detailed data is needed, it is difficult to find. Energy planning at national level, public and private, does not have a good quality.

LEAP is an easy program to use and with little requirements, although there were some problems when using it. The main conclusion from the scenarios is that both REN and ELECAR decrease carbon emissions. On the other hand, the costs of those scenarios are the highest. COAL is the cheapest scenario, but with more emissions.

One of the important conclusions of the study is that there is a surplus of installed capacity in Aragón. Coal thermal power plants have a low generation, and at the same time combined cycles are installed.

Key words: Energy, Aragón, System approach

Contents

Acronyms

C.T. Teruel	Teruel coal thermal power plant (Centrál Térmica Teruel, in Spanish)
CAZAR	Regional savings bank of Aragón (Caja de Ahorros de Aragón, Zaragoza y la Rioja, in Spanish)
CC	Combined Cycle
CNE	Energy National Commission (Comisión Nacional de Energía, in Spanish)
CNSE	Electrical System National Commission (Comisión Nacional del Sistema Eléctrico, in Spanish)
COAL	Coal priority scenario.
DG TREN	European Energy and Transport, trends to 2030, update 2007
DGA	Regional government of Aragón (Diputación General de Aragón in Spanish)
EIASA	Energías e Industrias Aragonesas, S.A (relevant company in the energy sector of Aragón)
ELECAR	Electric car scenario
EMESA	Electro Metalúrgica del Ebro, S.A (relevant company in the energy sector of Aragón)
ENCASO	Empresa Nacional Calvo Sotelo (relevant company in the energy sector of Aragón)
ENDESA	Empresa nacional de Electricidad, S.A (relevant company in the energy sector of Aragón)
ENHER	Empresa Nacional Hidroeléctrica Ribagorzana (relevant company in the energy sector of Aragón)
ERZ	Electricas Reunidas de Zaragoza (relevant company in the energy sector of Aragón)
GDP	Gross Domestic Product
GWP	Global Warming Potential
IAEST	Statistic Institute of Aragón (Instituto Aragonés de Estadística, in Spanish)
IDAE	Diversification and energy savings institute (Instituto para la Diversificación y Ahorro de Energía, in Spanish)
IEA	International Energy Agency
INE	National Statistics Institute (Instituto Nacional de Estadística, in Spanish)
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long range Energy Alternatives Planning system
MOVELE	Demonstration project for electric vehicles (MOVilidad ELEctrica, electric mobility in Spanish)
PAERA	Renewable Energy Action Plan in Aragón (Plan de Acción de las Energías Renovables en Aragón, in Spanish)

PEA	Energy Plan of Aragón (Plan Energético Aragonés, in Spanish)
PEN	National Energy Plan (Plan Energético Nacional, in Spanish)
PER	Renewable Energy Plan (Plan Energías Renovables, in Spanish)
PEREA	Evacuation Plan for the Special Regime in Aragón (Plan de Evacuación del Régimen Especial en Aragón, in Spanish)
RCS	Residential, Commercial and Service sector
REE	Spanish Electric Grid (Red Eléctrica Española, in Spanish)
REN	Renewable electricity scenario
RES-diagram	Reference Energy System-diagram, also referred in the text as Energy balance flow diagram
REVE	Wind energy regulation with electric vehicles (Regulación Eólica con Vehículos Eléctricos, in Spanish)
toe	Tonne of oil equivalents
UNESA	Association of the most important Spanish electrical companies (Unidad Eléctrica, S.A, in Spanish)

1 Introduction

1.1 Goal

The main goal of this work is to study the development of the energy system in Aragón and simulate and analyze some future options for its development.

The report is divided in two parts. The first part consists in a historical study to understand the technical system, the actors and the resources. In the second part models are used and results are analyzed and compared. The three energy models used are: the logistic curve, the energy balance flow diagram and the Long range Energy Alternatives Planning system (LEAP).

The results can be relevant for the regional government of Aragón (Diputación general de Aragón, DGA), university and even companies

1.2 Scope

System boundaries in this study are the same that the DGA uses. As shown in Figure 1 the parts of the energy system included are:

- Energy inputs. Primary energy is refers to energy forms that has not been converted or transformed[1] [2].
- Transformation includes electricity and heat generation, own consumption and distribution losses[3].
- Final energy demand[4].

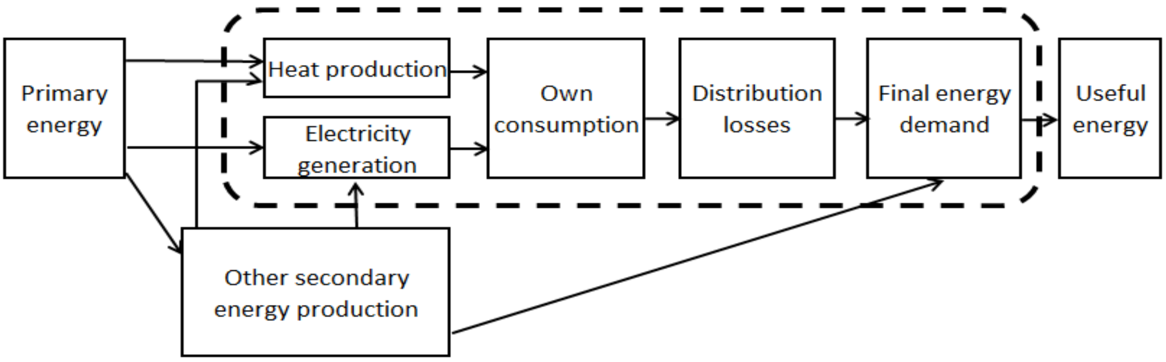

Figure 1. System boundaries for simulation in LEAP. The blocks inside the dashed rectangle are included in this study.

[1] Energy inputs are called primary energy in the DGA reports. Here the name is changed to avoid misunderstandings. Energy inputs include coal, natural gas, oil products, hydro, solar and wind energy, biomass, biofuels and geothermal.

[2] Primary energy includes coal, natural gas, oil, hydro, solar, wind, geothermal and biomass resources. Coal mining is the only extraction that occurs in Aragón. Not including it should not have a relevant effect in the result of the study, since the energy consumed is always under 3% of the total coal produced, except in 2008 when it is 5%. (Foro de la Industria Nuclear Española, 2010)

[3] Hydrogen generation and biofuels production are not included because there is no available data. Nevertheless, currently the fuels are a very small part of the energy system, therefore not considered to be relevant. This could change in the future.

[4] Device efficiency, e.g. bulb efficiency, is not included since there is no available data.

Electricity, gas and oil grids are not considered.

The geographical boundaries are Aragón limits. Nevertheless, Aragón is part of the energy system in Spain and Europe, and therefore policies and visions considered should be at three levels: regional, national and European.

In time perspective, the boundary for the scenarios and the logistic curves has been set to 2030.

Important limitations arise when studying the transportation sector. Due to data available, road and railway transportation cannot be separated. Fuel consumption is included in global scale, not by km or passenger. Stock variation of vehicles, airplanes or trains is not considered either, only total increase or decrease of consumption. A recommendation for further studies is to carry out a detailed study of the transportation sector.

Chapter 2 includes explanations about what a system and its development are, besides general information about Aragón and the current situation of the energy system in Spain.

The first part of the study includes from Chapter 3 to Chapter 6. Chapter 3 gives an overview of the data used in the historical analysis. Chapter 4 describes the development of the electrical system in Aragón. Chapter 5 explains the evolution of the electricity generation technologies in Aragón from 1992 to 2008 and Chapter 6 describes de evolution of the whole energy system during the same period.

The second part of the thesis includes from Chapter 7 to Chapter 15. Chapter 7 introduces the concept of energy modelling. Chapter 8 explains the logistic curve model and Chapter 9 the Energy Balance. Chapter 10 introduces LEAP, and then each scenario and results are presented in one chapter. Chapter 11 presents the business as usual scenario (BAU), Chapter 12 the coal priority scenario (COAL), Chapter 13 the renewable electricity scenario (REN) and Chapter 14 the electric cars scenario (ELECAR). To conclude this second part of the work, Chapter 15 presents the emissions and cost for each scenario. Finally Chapter 16 includes a comparison between the logistic curve and LEAP.

Chapter 11 comprises a discussion of the result and other issues considered relevant and Chapter 18 lists the conclusions.

2 Background

2.1 System approach, history and energy models

A system can be defined as a group of elements which are connected to each other and act in a coordinate way to achieve a goal. The elements in the system are affected by being in it, and the connection between them is important and has a function. This means that a system is more than the sum of the parts. The system approach focuses on studying the whole system instead of only the different parts, understanding the interrelationships between the entities (elements or components) of the system, to each other and to the whole so as to achieve a common goal (Maldonado, 2010).

The technological energy system is integrated in our society, which means that it is under social, political and private institutions conditions. This is sometimes called socio-technical system. In Figure 2 a simplification of the socio-technical energy system is represented. From this point of view it can be explained why the historical evolution of a system is important. Technique, society, politics and private institutions change together during the development of the system. A positive feedback affects all parts of the system. Positive feedback result in a path-dependent evolution with a last consequence: the lock-in (Unruh, 2000).

A path-dependent evolution means that the development of a system is dependent on its past. The lock-in is the situation, at the maturity of the system, when there is a dominant technology and the system is in quasy-stable equilibrium. Path-dependent evolution and lock-in cause that the dominant technology is not necessarily the best one, but the technology that has the "correct" history (Unruh, 2000). Hence, this is a very important issue to take into account when looking in to the future, and can only be understood studying the history. Besides, this positive feedback, path dependent evolution and final lock-in is behind the logistic curve and its characteristic shape (see Section 8 for a more detailed explanation of the logistic curve).

Once that the evolution of a system is understood the system has to be described at a point of time, and this can be done building a model. As systems are usually complex, models represent them in a simpler way, usually focusing in some of the characteristics. Thus, a model is a simplify picture of the reality, NOT the reality. Here is where the energy balance, also known as Reference Energy System diagram (RES-diagram) play its role[5].

An energy balance is a graphic model of the state of the energy system at a point of time. It shows energy consumers, energy technologies, energy carriers and energy sources. Energy flows are an important part of an energy balance, showing how parts of the system are linked. Summing up, the energy balance helps to understand the system, the interactions between the parts, and its behavior.

Historical development is also important for scenario development, since it is needed to make consistent assumptions of different possible future developments. Finally, the energy balance and the scenarios are related by using the energy balance of Aragón in 2008 as base data to simulate the future scenarios in LEAP.

[5] The name "energy balance" has been chosen since it has been found in literature and it is the direct translation of the Spanish name used by the DGA, "balance energético".

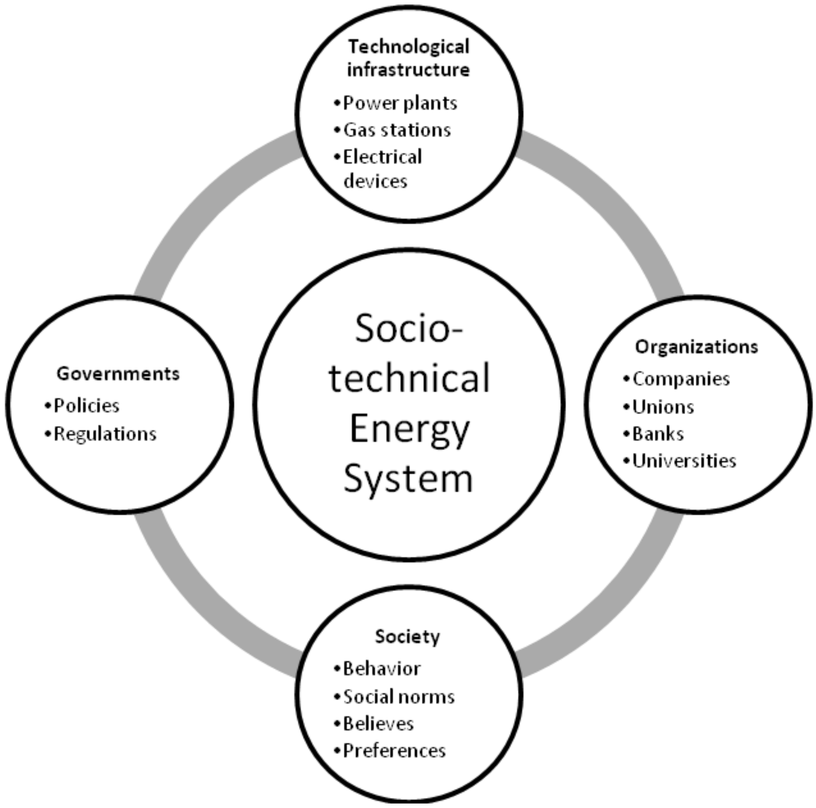

Figure 2 *Parts of the socio-technical energy system. Source: own elaboration from the theory in (Unruh, 2000)*

2.2 Aragón

2.2.1 General data

Aragón is situated in the northeast of Spain, as shown in Figure 3. It is bounded by Valencia and Catalonia to the east and by France to the north. Zaragoza, which is the capital of the region, is around 300 km from Barcelona, Madrid and Bilbao. Thus it is considered a crossroads for many infrastructures in Spain.

Aragón has an area of 47,720 km^2. Aragón is divided into 3 provinces: Huesca, Zaragoza y Teruel (see Figure 3). Population in the year 2008 was slightly above 1.3 million inhabitants, slightly below 3% of the Spanish population. The province of Zaragoza had 0.9 million inhabitants, Huesca had 225,000 inhabitants and Teruel only 146,000. Urban population represents 68% of the total population (IAEST, 2009).

The relief system in the region can be described as two mountain ranges, the Pyrenees at the north and the Iberian system to the south, which create the valley of the river Ebro in between them. The Pyrenees have high altitudes, steep slopes and deep valleys, and some of them are used for hydropower. The Iberian system is less steep. The river Ebro is the most important river in Aragón. It is the largest river in Spain in volume, and the second in length High winds are a characteristic of this area.

The climate in Aragón varies highly depending on the area, from subtropical steppe to mountain climate. The most important characteristics of the climate in Aragón are: aridity, irregular rainfalls, irregular temperatures, seasonal contrast and strong winds in surface. This conditions lead to high energy demands, both in winter and in summer. However, climate conditions also make Aragón a good territory for solar power, since there are high values of solar radiation, and wind power, especially in the Ebro valley (see Annex 1 for solar and wind potential maps).

Figure 3 *Situation of Aragón in Spain. In the down-right corner the province division is shown. Source: Google maps, (DGA)*

2.2.2 Economy

GNP in Aragón in year 2008 was 34,371 million Euros, approximately 3% of the Spanish GNP. The GNP per capita was 26,323 Euros, slightly above Spanish average. The percentage of each sector in the GNP for Aragón and Spain during year 2008 is represented in Figure 4 (DGA, 2009d).

The most important sector is the service sector, which accounts for 62% of the GNP. Commerce is the most important activity in this sector (DGA, 2009d).

Industry, energy and construction represent together 33%. Regarding industry, the most important activity is the manufacturing of automobile parts and materials. The General Motors factory in Zaragoza plays a major role, followed by domestic electrical appliances industries and paper industries. Industrial sector is mainly located in Zaragoza. Energy is an important subsector in Aragón. In 2008 electricity was the 3rd most important industrial product from Aragón. Construction has been a very important sector during last years in Aragón and Spain, but it has decreased its importance with the crisis (DGA, 2009d).

Primary sector represents only 5% of the GNP, although it was the most important sector in the region until the 70s. Today, the primary sector is still more important in Aragón than in other parts in Spain, as it is shown in Figure 4.

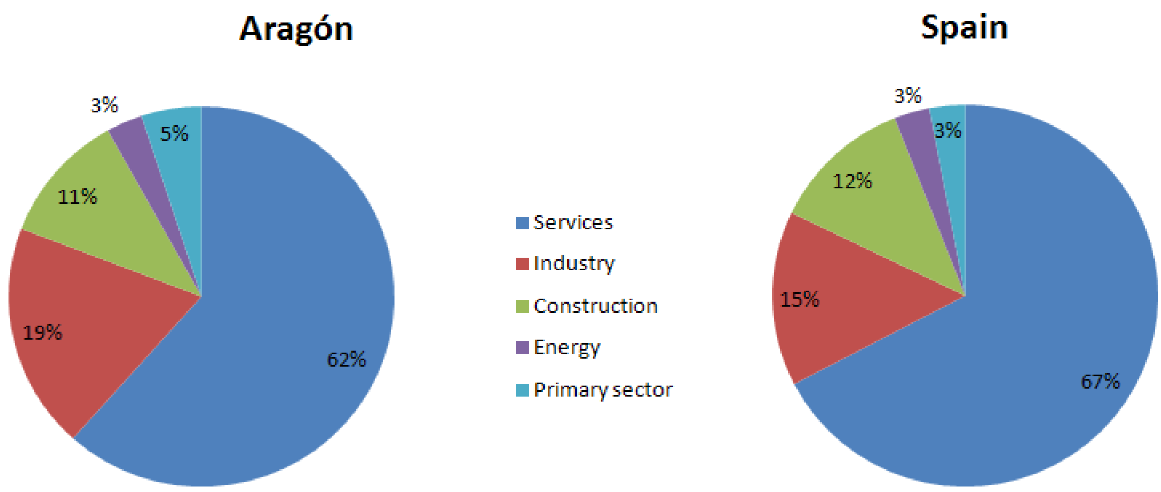

Figure 4 GDP by sectors in 2008 in Aragón and Spain. Source:(IAEST, 2009).

2.3 Current situation of the energy system in Spain

2.3.1 Primary energy

Primary energy consumption in Spain was 142,070 ktoe in 2008. It decreased 3% from 2007, due to decrease in final demand and the substitution of coal thermal power plants by combined cycle, wind and solar in electricity generation (Ministerio de Industria, 2009). Aragón accounts for 4.6% of the primary energy consumption in Spain.

Fuel shares in total primary energy consumption in Spain are represented in Figure 5. Oil is the most important energy source, accounting for 68,110 ktoe. Oil primary demand decreased 4% during 2008. Natural gas is the second most important primary energy source. Natural gas consumption increased 10% in 2008, reaching 34,783 ktoe. Nuclear energy is the third primary source. The use of nuclear energy increased 7% in 2008, since in 2007 some nuclear power plants were not functioning. Coal primary demand decreased 32% in 2008. The decrease was mainly caused by the change in electricity generation mix. Finally, renewable energy primary consumption was 10,843 toe (Ministerio de Industria, 2009).

In 2008 Spain imported 78% of the primary energy consumption: 100% of the natural gas used, 99% of the oil and 69% of the coal. Spain exports exported 949 ktoe on electricity in 2088.

2.3.2 Energy transformation

Figure 6 shows electricity generation by sources in Spain. Total installed capacity in 2008 was 95,177 MW, and electricity generation was 316,850 GWh. Aragón accounts for 7.4% of the installed capacity and 7.1% of the electricity generation in Spain.

Heat generation is not as well documented as electricity generation. Heat is produced basically in cogeneration plants. Most of the cogeneration plants are associated with industries with high heat demands. However, the trend shows an increasing interest in cogeneration from the service sector, for example in commercial centres. Total heat produced in cogeneration plants in 2009 was 4,125 ktoe (IDAE, 2010a). Heat is also produced in a small share by low temperature solar thermal (129 ktoe in 2009) and geothermal (8 ktoe in 2009)

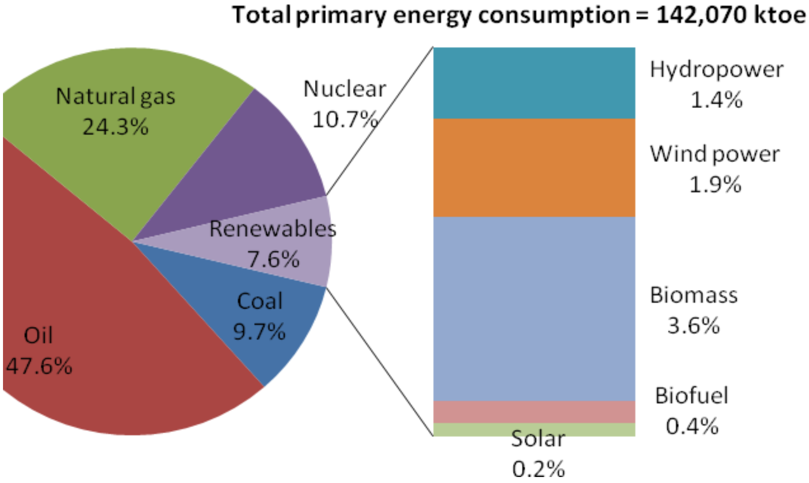

Figure 5 *Total primary energy consumption by sources in Spain in 2008 (Ministerio de Industria, 2009)*

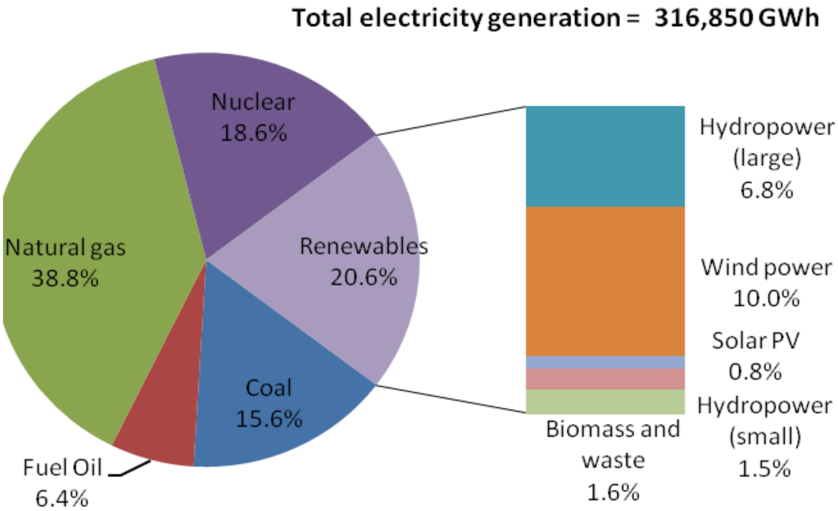

Figure 6 *Total electricity generation by sources in Spain in 2008 (Ministerio de Industria, 2009)*

2.3.3 Final energy

Final energy demand was 105,347 ktoe in 2008, decreasing 2% from 2007. Aragón consumes 3.8% of the Spanish final energy.

Final demand by fuels is represented in Figure 7. Oil products are the most important group of fuels, almost 100% of the final energy consumption of the transport sector and part of the industrial and the residential-commercial-service sector (RCS).

Natural gas final consumption was 17,273 ktoe in 2008. Natural gas is mainly used in the industrial sector.

Electricity is the second most demanded energy carrier. In 2008 electricity consumption was 22,112 ktoe. During year 2008 there was a decrease of 0.2% in electricity demand, due to decrease of industrial activity and improvements in efficiency.

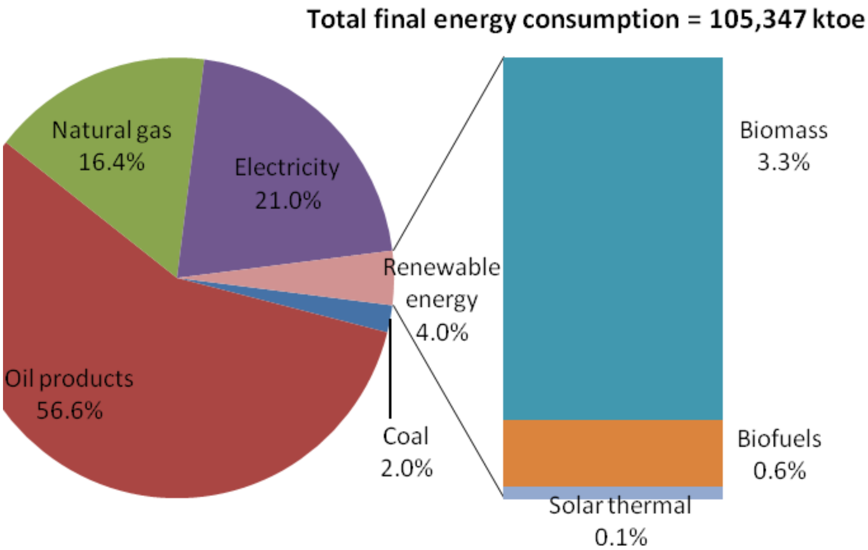

Figure 7 Final energy consumption by sources in Spain in 2008 (Ministerio de Industria, 2009)

3 Data

The analysis consists in a literature review, gathering data and identifying main components, resources, actors and development of the system.

The most important references used for the historical description are listed in Table 1.

Table 1 Most important references for the first part of the report.

Source name	Description
ERZ (1910-1990). El desarrollo del sector eléctrico en Aragón[6] (Germán, 1998).	Basis for the historical analysis until 1985.
Estructura energética de Aragón. Los balances energéticos regionales en el periodo 1984-1997[7] (DGA, 2000).	Study that encloses extensive data and Energy balances from year 1992 to 1997.
Los balances energéticos regionales en el periodo 1998-2004. Datos y análisis para una estrategia energética[8] (DGA, 2005a).	Study that encloses extensive data and simplified Energy balances from year 1998 to 2004
Boletín de Coyuntura Energética en Aragón[9].	Energy Reports published every 6 months from 1998 by the DGA. Include simplified Energy balances.
Reports, articles, laws, and other governmental documents.	Basic information about regulation, taxes and prices. All available in internet.
Instituto Nacional de Estadística[10] (INE). Instituto Aragonés de Estadística[11] (IAEST)	Databases available in internet. Used for demography and to fill data gaps.

[6] ERZ(1910-1990). Electrical Sector Development in Aragón
[7] Energy Structure of Aragón. Regional Energy Balances for the period 1984-1997.
[8] Regional Energy Balance for the Period 1998-2004. Data and Analysis for an Energy Strategy.
[9] Energy in Aragón, periodic reports
[10] National Statistical Institute)
[11] Statistical Institute of Aragón

4 Electrical system historical development

If not stated, information provided in this section comes from the book *ERZ (1910-1990). The Development of the Electrical Sector in Aragón (Germán, 1998).* Following the structure of this book, the explanation of the historical evolution is divided in seven subsections:

1. Before 1911. Creation of the first companies.
2. From 1911 to 1936. Before the Civil War
3. From 1940 to 1959. Post-war period
4. From 1960 to 1975. Development of the sector
5. From 1976 to 1985. Oil crisis
6. From 1985 to 1998. Reorganization before liberalization of the electric sector.
7. From 1998 to 2008. Liberalization and new technologies in: cogeneration, renewable energy sources and combined cycle.

4.1 Before 1911: Creation of the first companies.

In 1875, Xifrá and Dalmau (engineer and business man respectively) introduced electricity in Spain. They installed the first power plant in Barcelona to provide electricity for lighting to several shops. The power plant had four gas engines of 50 hp and four Gramme machines of 400 volt-amperes.

In general, private investors and engineers drove the Spanish electric sector with private initiatives until the 50s. Foreign companies also became involved in the foundation of electric companies, investing money or selling their technology in Spain.

4.1.1 Electric system origins in Aragón

Electricity was first used in Aragón in the city of Zaragoza in 1883 to provide lighting to some cafés and a shop, as it was considered fashionable. Two companies provided the service: Compañia Aragonesa de Electricidad[12] and Electra Peral Zaragozana[13].

When introduced, electric lighting competed against gas lighting. Gas lighting was spread in Zaragoza and had an agreement with the city council for 50 years when the first electrical utilities where created. The company providing gas lighting was French, called Fabrique de Gaz de Saragosse[14], owned by the bank Credit Lyonais.

Demand was mostly located in Zaragoza. During the first years electricity was used for lighting. Later, from the beginning of the 20^{th} century, it started to be used for motive force. Table 2 shows the evolution of installed capacity, number of power plants and the share of technologies in Aragón in 1901 and 1904.

The development of the electrical system during the first years was constrained by the impossibility of long distance transmission of electricity. The alternative current and the transformer changed the situation at the beginning of the 20^{th} century. Then, hydropower became the dominant technology, since it was cheaper and easier to use than steam and gas and Aragón had enough hydrological resources. According to Germán, the second transmission of electricity in Europe took place in Zaragoza in 1901. Electricity was transmitted 3 km in 1901. Three

[12] Aragonese Company of Electricity
[13] Electra Peral from Zaragoza, where Peral is the surname of the foundator.
[14] Gas Factory from Zaragoza

years later, in 1904, the first transmission at 30,000 volts took place also in Zaragoza, and electricity was transported 96 km (Germán, 1998).

Table 2 *Installed capacity, number of power plants and share of technologies in Aragón in 1901 and 1904. Source: (Germán, 1998).*

Year	Installed capacity (kW)	Number of power plants	Thermal (%)	Hydro (%)	Thermal & Hydro (%)
1901	3011	49	37.6	36.1	26.3
1904	4162	83	32.6	45.8	21.6

In 1883 the first aragonese companies were founded, as said before: Compañia Aragonesa and Electra Peral. Compañia Aragonesa, focused on hydropower, while Electra Peral focused in thermal power. In 1901, two new companies were founded in Zaragoza: Fuerzas Motrices[15] and Teledinámica[16], both focusing in hydropower. Fuerzas Motrices joined Compañia Aragonesa and Electra Peral in 1904, and they provided electricity for the trams in Zaragoza. Meanwhile, Teledinámica opened a calcium carbide factory in Huesca, next to their power plant.

Finally, in 1911, the four companies merged in Electricas Reunidas de Zaragoza[17] (ERZ), which had around 9,580 kW capacity, almost all of it hydropower. ERZ also owned the calcium carbide factory. ERZ has been the most important electrical company from Aragón.

4.2 Before de Civil War (1911- 1936)

Spanish electrical system had an important development before the civil war. This development occurred mainly in Aragón and Catalonia. However, Spanish development was not as important as in other countries. In 1934, the electricity generated in Spain was 150 kWh per person, while in Italy it was 258 kWh/person, in Germany and United Kingdom it was 450 kWh/person and in the United States 675 kWh/person.

4.2.1 Electrical system in Aragón

The electrical system in Aragón was dominated from big Spanish companies that used hydrological resources from Aragón to generate electricity and transport it to other regions.

The most important Spanish companies that installed power plants in Aragón where:

- Cooperativa del Fluido Eléctrico[18]. Produced electricity in east Pyrenees and delivered it to Barcelona. Their installed their main power plant in Aragón in 1919, with 8.8 MW of installed capacity. It was increased to 26 MW in 1921.

[15] Motive Forces
[16] Teledinamic
[17] Reunited Electrics from Zaragoza
[18] Cooperative of Electric Fluid

- Electro Metalúrgica del Ebro[19] (EMESA). The company had a calcium carbide factory as well as electricity generation facilities. Therefore the company produced for the factory and delivered the rest of the electricity to Barcelona. A small amount was sold to ERZ.
- Hidroeléctrica Iberica[20]. Produced electricity with hydro power in the central Pyrenees and delivered it to Bilbao. The first power plant was installed in 1923, having 28 MW of installed capacity.
- Energía e Industrias Aragonesas[21] (EIASA). Their first power plant started operation in 1921 with 6 MW capacity. Although the investors were a French chemical group, the industries and electricity remained in Aragón.

ERZ, as the main aragonese actor, provided electricity mainly in Zaragoza. The company started also to specialize in electricity distribution, buying electricity to local utilities and EMESA.

Small local electrical utilities played also a major role. Local utilities usually had small hydropower plants close to the rivers, to cover local demand.

Table 3 shows the most important companies in Aragón at the beginning of the 20s, and Table 4 summarizes the situation of the electric sector in Aragón in 1935. Both tables show that the development of the system during this period lead to an electrical system dominated by companies from outside the region.

Table 4 also shows consumption of electricity in 1935. From the total generation, 349 GWh were exported. In fact, Aragón generated 18% of the electricity in Spain, while the population was only 4.4%. Consumption per capita was around 220 kWh, above Spanish average of 150 kWh. The reason for this is that Aragón had very low population, but the region was one of the main producers of chemicals.

Table 3 Most important companies in Aragón at the beginning of the 20s. Source: (Germán, 1998)

Name	Installed capacity (kW)	Number of power plants	Thermal (kW)	Hydro (kW)
Cooperativa del Fluido Eléctico	23,289	3	0	23,289
ERZ	9,516	3	0	9,516
EMESA	2,944	1	0	2,944
Local utilities	7,855	142	434	7,421
Total in Aragón	43,604	149	434	43,170

19 Electric Metallurgic of Ebro
20 Iberian Hydroelectric
21 Energy and Industries from Aragón

Table 4. Most important companies and electricity consumption in Aragón in 1935. Source: (Germán, 1998).

Name	Installed Capacity (MW)	Generation (GWh)	Electricity destination	River
Hidroeléctrica Iberica	98	168	Basque Country	Cinca
EIASA	15	99	Self-consumption	Gallego
Cooperativa del Fluido Eléctrico	30	96	Catalonia	Esera
ERZ	16	83	Aragón	-
EMESA	19	81	Catalonia (50%),self-consumption, ERZ	Ebro
Other companies	18	52		
Total in Aragón	196	579		
Total electricity consumption (GWh)	229			

4.3 Post war period (1940-1959)

4.3.1 Spanish electrical sector

The evolution of the installed capacity and electricity generation in Spain can be divided in two periods. The first period, during the 40s, the growth was slow and generation was dependent on the rain. From 1940 to 1945 the installed capacity in Spain grew 2% yearly, increasing to 6.8% yearly from 1945 to 1950. In the second period, the 50´s, the growth was important, more than 10% annually, and the fluctuation due to rain disappeared.

The Civil War (1936-1939) did not seriously affect the existing energy infrastructure, but it caused a building halt until 1942. There were three factors affecting Spain. First, during the war and just after it, it was difficult to obtain machinery and materials. Second, the price of the electricity did not change until 1953 while the inflation was significant. And third, until 1945 the government did not participate actively in the sector, neither encourage private initiative. As a result, there were restrictions on consumption from 1944 to 1953. Despite the problems that installed capacity had to meet demand, electricity consumption grew 7.9% yearly.

A number of changes were made from 1945, and in 1959 the installed capacity had been multiplied by four. Besides, the losses in transmission were decreased and the connections between different Spanish areas were improved. Therefore restrictions in consumption were not usual from 1953, and disappeared in 1959.

In 1944 the Unión Eléctrica Sociedad Anonima[22] (Unesa) was created. Unesa was an association of 17 electrical companies, which covered 80% of the electricity generation in Spain. Unesa aimed to organize and rationalize the Spanish electricity market without state intervention. Spain was divided in 6 zones. Aragón was one of the zones, with two companies: ERZ and EIASA. In 1952 Unesa organized a centralize office to control de electricity system at national level. It also worked as a lobby. As a result, the electrical sector worked as an oligopoly, with a division of the Spanish territory between companies. Unesa still exists today as an association of the most important electrical utilities in Spain.

From 1945, the government started to act to solve the lack of electricity, buying some companies with problems and creating public companies. In 1953, the government introduced "the Unified Price" of electricity. The "Unified Price" was a standard price of electricity, fixed for all the companies regardless the cost of their generation. This new price included subsidies for thermal electricity and for new power plants. The subsidies were around 42% of the price. The goal of the government was to increase the number of thermal power plants, since the country was very dependent on hydropower. Building of new plants was encouraged, and the economic advantage to build factories next to the generation facilities disappeared.

4.3.2 Electrical system in Aragón

Electricity generation in Aragón was between 10% and 14% of the Spanish electricity, while aragonese population was 4.1% of the Spanish population in 1940, and 3.6% in 1960.

Two of the companies created by the government were established in Aragón. ENCASO built a thermal power plant in Zaragoza, called Escatrón, with 172.5 MW. The construction started in 1952 and ended in 1958. The energy was sent outside Aragón, but ENCASO became the most important electricity producer in Aragón. The second company was ENHER, which installed 48.4 MW of hydro power in Aragón. The electricity was also use outside the region.

The main characteristic of the electricity market in Aragón was that different companies were the main producers and the main distributors of electricity. Thus companies can be divided in two groups: Table 5 shows the main producers in Aragón, and Table 6 the main distributors. Encaso and Iberdureo are two of the main producers. But they transported the electricity to other regions, so they have no importance as distributors in Aragón.

The two aragonese companies already in operation, ERZ and EIASA, were main producers of electricity and the most important distributors in Aragón (see Table 5 and Table 6). They built new power plants during this period. ERZ main action was Aliaga, a 46 MW thermal power plant situated in Teruel. Aliaga was built from 1950 to 1958. ERZ built also 12.5 MW of hydropower. EIASA continued building in the central Pyrenees, a total of 48.8 MW. Regarding their role as distributers, ERZ was the most important distributers in terms of territory, and EIASA in terms of electricity distributed. ERZ shows an important expansion during this period. Starting in Zaragoza province, at the end of the period it controlled most of the region. On the other hand, EIASA continued to be a local producer, but its main consumers where factories with very high electricity consumption.

ERZ was helped by Caja de Ahorros de Aragón, Zaragoza y la Rioja[23] (CAZAR) to carry out the expansion, both for increases of debt and for increases of capital. In 1952 the president of

[22] Electrical Union Corporation
[23] Savings Bank from Aragón, Zaragoza and La Rioja

CAZAR became part of the board of directors of ERZ and the bank bought bond certificates of the company.

Table 5. Main generation companies in Aragón in 1959. Source: (Germán, 1998)

Company	**Generation GWh**	**%**	**Installed capacity MW**	**%**
ENCASO	536	28.9 %	173	28.6 %
ERZ	291	15.7 %	88	14.5 %
Iberduero (former Hidroeléctrica Iberica)	251	13.6 %	102	16.9 %
EIASA	248	13.5 %	63	10.4 %
Total main electricity producers	1326	71.7 %	426	70,4 %
Other companies	526	28.3%	177	29.6%
Total	1852	100%	603	100%

Table 6. Main distribution companies in Aragón in 1959. Source: (Germán, 1998)

Company	**Distribution GWh**	**%**	**Area**
EIASA	273	40.2 %	Central Pyrenees
ERZ	272	39.9 %	Rest of Aragón
Total main electricity distributors	545	80.1 %	-
Other companies	135	19.9%	Local distributors
Total	680	100%	-

Figure 8 shows the evolution of installed capacity, electricity generation and electricity consumption in Aragón from 1940 to 1959. The two periods already distinguished when explaining Spanish development are observed in this graph. During the 40s the economic situation and the restrictions to demand halted the development of the electric system. The situation changes during the 50s, when the economic situation improved, restrictions to consumption were removed and the new electric tariff was introduced. New thermal power plants build during the 50s are easily identified in the diagram. The rest of the increases in installed capacity are due to hydropower plants. Electricity produced grew as installed capacity, not as electricity consumption. This is because Aragón exported most of the electricity produced.

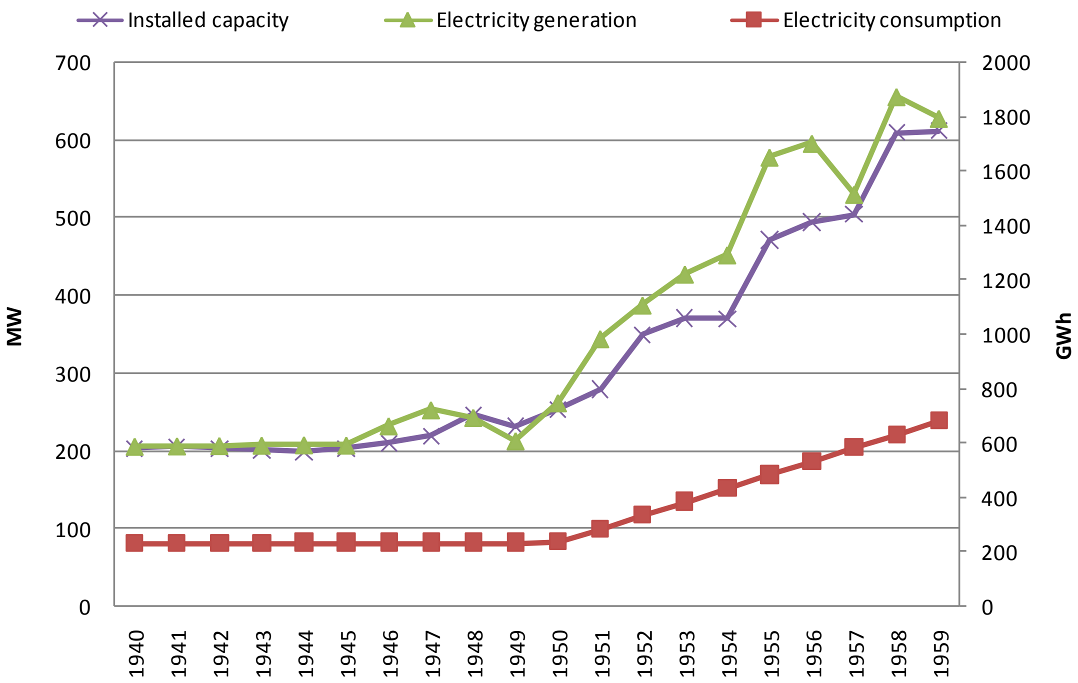

Figure 8 *Installed capacity, electricity generation and electricity consumption in Aragón from 1940 to 1959. Installed capacity and electricity generation are interpolated until 1944 using values from 1935 and 1944. Consumption data is interpolated using values from 1935 and 1959. (Germán, 1998)*

4.4 Development of the electrical sector (1960-1974)

Spanish economy underwent an important growth during the 60s and the first 70s. GDP grew 7% yearly. Primary energy consumption grew more than the GDP, 8% yearly. This was mainly achieved by increasing oil consumption. from 29% to 69% of the primary energy. Coal contribution to primary energy consumption decreased from 41% to 15%.

4.4.1 Spanish electrical system

Electricity was very important during the economic growth. The electrical sector itself was one of the sectors that improved the most. In comparison with other European countries, there were very few factories building their own power plants.

The government continued to regulate the sector, continuing the process started in the 50s. In 1960 imports and exports of electricity were deregulated, and more subsidies were introduced to help the construction of new power plants. In 1964 the law for nuclear energy was approved. The first nuclear plant was installed in 1968. However nuclear power has never arrived to Aragón.

The antecedent for the national energy plans was the Plan Eléctrico Nacional[24] published in 1969. It included electricity demand forecasts, as well as plans to build new power plants. Forecasts were too high, being the real electricity consumption half of the forecasted consumption for 1974. However, this plan had some good results, as it lead to a more standard

[24] National Electric Plan, 1969

sector and developed the distribution and transmission lines. Regional systems became completely connected in the Red General Peninsular[25]. Moreover, Spain was connected to France.

Following the national electric plan, in 1970 a new pricing method was introduced. The price was divided in two parts: one part proportional to contracted electric power and a second part proportional to kWh consumed. Nevertheless, this method did not mean an increase in the prices, which in the whole period only increased in 1963 and 1974. Thus, in 1974 the real price of electricity was half the real price in 1959.

Installed capacity increased with hydropower, thermal power and nuclear power. In 1960 there were 6,597 MW installed, which grew to 24,337 MW in 1974. Electricity generation in Spain grew from 18,625 GWh to 80,865 GWh during this period.

4.4.2 Electrical system in Aragón

During this period the most important characteristics of the electrical system in Aragon were: the construction of big dams, the improvement of the distribution grid and the increase of consumption, both in the industrial and in the domestic sector.

Division between generation utilities and distributors continued to exist during this period. Table 7 shows the main companies in the generation branch and their installed capacity, as well as the total installed capacity and electricity generation and consumption. ENHER became the most important actor. This was achieved by building the biggest dam in Aragón with 310 MW and some smaller plants, all in the same river. ERZ constructed also hydropower plants, including the first pumped-storage plant, called Ip.

The impact of the dams constructed in Aragón cannot be considered positive for the region. Villages had to be moved and technology used was bought outside Spain. Jobs created during the construction work were a benefit, but only temporary.

Thermal power plants also developed. ERZ bought 50% of the thermal power plant in Escatrón. In 1972 Endesa took over ENCASO. Therefore Escatrón was controlled 50% by ERZ and 50% by Endesa, in a joint venture called Termoeléctrica del Ebro[26]. A new company was created in Teruel, called Unión Térmica[27]. It built a new thermal power plant in Teruel in 1970, called Escucha, with 160 MW. This company was part of a group with interest in the mines in Teruel. Lignite consumption increased from 283 kton to 1,532 kton.

Regarding distribution, a major change happened: all the relevant companies in Aragón merged with ERZ. The result was that in 1967 ERZ distributed 70% of the electricity consumed in the region. On the other hand, the companies producing their own electricity represented during this period from 15% to 20% of the electricity consumption. The most important companies of this type where EIASA and Hidronitro Española.

Distribution and transmission grids improvements were important in Aragón. Several substations were built, and the region was connected to France.

Figure 9 shows the evolution of electricity consumption, electricity generation and installed capacity in Aragón from 1960 to 1974. Installed capacity increases due to new hydropower plants, and the new thermal plant Escucha, in 1970. Electricity consumption in Aragón grew

[25] Peninsular General Grid
[26] Termo-electric from the Ebro, where Ebro is the river next to Escatrón power plant.
[27] Thermal Union

9% yearly, 1% less than the Spanish average. From 1973 the oil crisis started to halt the increase in electricity consumption. However the most important effects came from 1979.

Table 7. Main companies´ installed capacity, total electricity generation and total consumption in Aragón in 1974.

Company	**Installed capacity MW**	**%**
ENHER	515	32.3
EIASA	240	15.1
ERZ	225	14.1
Termoeléctrica del Ebro	173	10.8
Unión Térmica	160	10
Other companies	280	17.7
Total	1593	100
Electricity generation (GWh)	5166	100
Electricity consumption (GWh)	3015	58

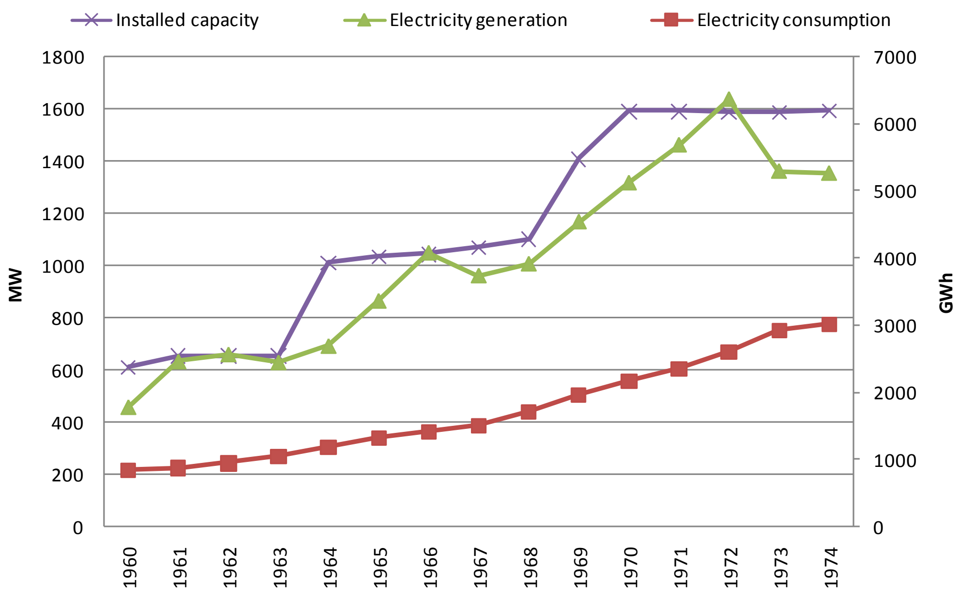

Figure 9 Installed capacity, electricity generation and electricity consumption in Aragón from 1960 to 1974. (Germán, 1998)

4.5 Oil Crisis (1975-1985)

The oil crisis affected Spain later than other countries due to the political situation. Besides, inflation was also a problem. In 1975 it was 16%, it reached its peak in 1977 with more than 25% and at the end of the period inflation was around 9% (Ariño and Canela, 2002). However, GDP and energy consumption continued growing, although in much lower rates than in the previous period. GDP grew 1.8% yearly, and energy consumption increased 2% yearly (compare with 7% and 8% respectively in the previous period).

Oil was substituted by coal for electricity generation. Thus, oil lost part of its share in the total primary energy consumption, decreasing from 69% in 1974 to 50% in 1984. Coal consumption share grew from 15% in 1974 to 26% in 1984.

4.5.1 Spanish electrical system

Electricity generation and consumption of electricity increased 4.4% yearly. Electricity generation was 127,216 GWh in 1985. Three national energy plans (PEN from the Spanish acronym) were approved during this period, one in 1975 (PEN-75), the second in 1978 (PEN-78) and the third one in 1983 (PEN-83).

According to Mir, the first plan aimed to follow the action of the European countries, showing the need of having a comprehensive energy planning. The PEN-75 was expected to be valid from 1975 to 1985. The main objective was to decrease the use of oil products. To do that the idea was to increase nuclear share in the electricity generation from 7% in 1975 to 56% in 1985, and cover all the installed capacity increases from 1985 with nuclear power. A major failure of this plan was that oil prices were heavily subsidized; therefore there was no incentive to decrease oil consumption. Besides, the plan did not include forecasts of changes in oil prices (Mir, 1999).

After Franco died and Spanish political situation changed, a revision for this plan was considered necessary and the new government made the PEN-78. Demand and offer were also forecasted considering that fuel substitution could only occur in the electrical system. However, in practice, the majority of decisions concerning the ten following years were already taken, and therefore the demand had to follow what the offer dictated (Mir, 1999).

An important contribution of the PEN-78 was the creation of a basis for the Special Regime.. Although the Special Regime as such was created in 1994 (see section 4.6), the PEN-78 leaded to a law for Energy Conservation that came into force in 1980. The Energy Conservation law aimed in promoting self-generation and small hydropower, with less than 50 MW capacity. The basis of the Special Regime included in the Energy Conservation law were (UNESA, 2004):

- Power plants included in the Energy Conservation law will have guaranteed the access to the distribution network.
- The distribution company had to buy the electricity produced, and in case of self-generation, the electricity surplus.
- The electricity price is fixed by the government in order to encourage this type of installations.

After the elections in 1982, the new government considered that a new energy plan should be carried out. The PEN-83 main ideas were to slow down the increase of installed capacity, to encourage energy efficiency and diversification of fuels (Mir, 1999). As previous demand forecast were too high, nuclear plants constructions were halted to adjust to the new demand predictions. Demand and offer were modeled for the first time together, using an optimization model that considered technology and economics.

PEN-83 also included the nationalization of the electricity transmission grid and the creation of new company to control it: Red Eléctrica de España[28] (REE). The aim of REE was to organize electricity transmission in a more efficient way, and to start integrating it with the natural gas grid (Mir, 1999).

In general, electrical utilities increased their debt, due to the big investments needed, the inflation, debt in other currencies and the increase in the cost of materials and machinery. As a result, a number of companies had an unbalanced financial situation, and in 1984 the government proposed an asset swap plan. The plan was carried out in 1986 (see section 4.6.1).

Total installed capacity grew from 24,337 MW in 1974 to 41,846 MW in 1985. The PEN-75 planned 24 nuclear power plants, but only three were built, two with 1,860 MW and one with 974 MW installed capacity. In hydropower the focus was on modernization of old installations and pumping-storage. Transmission and distribution lines were also improved.

During the 10 years of this period there were fourteen increases in the electricity tariffs, all of them between 5% and 22%. However, due to the high inflation, real prices of electricity were always below the ones in 1959. Night tariffs were introduced.

4.5.2 Electrical system in Aragón

The oil crisis increased the electricity generation with coal, which affected Aragón since there was lignite in the region. Regarding hydropower, most of the works where focused in restoration of old hydropower plants.

Table 8 shows the installed capacity, electricity generation and electricity consumption in Aragón in 1985. Endesa became the company that generated the most electricity when the Central Térmica Teruel[29] (C.T. Teruel) was built. C.T. Teruel consists in three groups of 350 MW each. The first group was finished in 1979, and the last group in 1981. ENHER remained the second company with more capacity installed after constructing a new pumped-storage hydropower plant with 246 MW.

ERZ was not in the group of the most important generating companies, since during this year it only had 6% of the installed capacity. ERZ did not install any new power plant, Aliaga was closed and Escatrón had to decrease working hours due to environmental reasons. However, ERZ was the most important company in Aragón, both in sales and number of employees, until 1982 when General Motors opened its factory in Zaragoza.

Figure 10 shows the evolution of installed capacity, electricity generation and electricity consumption in Aragón from 1975 to 1985. In 1978 and 1979 the increase in capacity installed is due to the construction of C.T. Teruel. Electricity demand grew 3.5% in yearly average, under Spanish average of 4.4 %, and decreased during the second half of the period due to delayed effects of the oil crisis. From 1980, more than 60% of the electricity produced was exported. In 1982 the General Motors' factory in Zaragoza became the most important electricity consumer in Aragón, with a yearly average of 200 GWh per year.

[28] Spanish Electric Grid
[29] Thermal Power Plant Teruel

Table 8. Installed capacity, electricity generation and consumption in Aragón in 1985.

Company	Installed capacity MW	%
ENDESA	1050	38
ENHER	761	27.6
EIASA	292	10.6
Other companies	657	24.8
Total	2760	100
Total electricity generated (GWh)	11706	100
Total electricity consumption(GWh)	4433	38

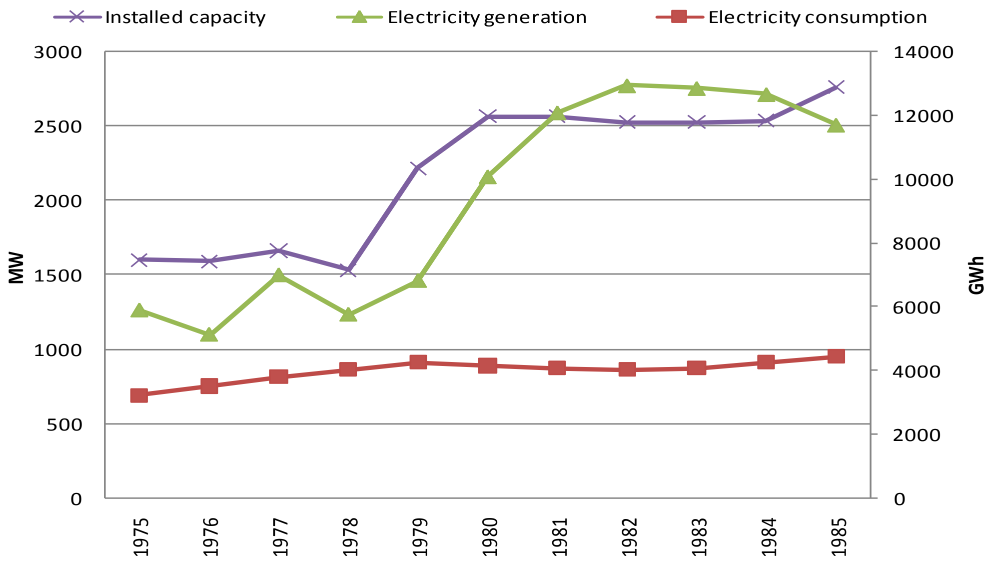

Figure 10 Evolution of electricity consumption, electricity generation and installed capacity in Aragón from 1975 to 1985. (Germán, 1998)

4.6 Before liberalization of the electric sector (1986-1997)

In 1985 Spain started to recover from the crisis. A key event in this period was the incorporation of Spain to the European Union in 1986. Being part of the European Union forced an institutional change, which included liberalization of the energy system. This section explains the development of the electric system since the end of the crisis until the liberalization in 1997.

4.6.1 Spanish electrical system

As explained in the previous section, in 1986 there was a reorganization of the electric system in Spain. The government proposed an asset swap, which was carried out in 1986 after a negotiation with Unesa. The aim of the asset swap was to optimize system cost and management.

In 1987 a new law was approved to guaranty that electricity tariffs will provide enough benefits to recover the investments made to build new power plants. The law introduced a new method to calculate electricity price, using "standard costs". Each component use to generate and distribute electricity was assigned a standard cost. Final consumer price was calculated dividing the total standard cost by the expected demand. The total income from the electricity sales was distributed between the companies according to the "standard costs" that each company had, regardless of their real costs. Thus, this system encouraged the companies to reduce costs. The possibility to adjust prices when there was an error in the prediction of cost was also introduced. (Arocena et al., 2002, CNSE, 1997)

In order to become part of the European unique market, the government considered that there was a need to create powerful companies. The government's goal was to create stable big companies, and maintain them Spanish to facilitate control (Arocena et al., 2002, CNSE, 1997). So from 1991 a new reorganization of the electrical utilities was made. As a result, four big companies were created. Endesa was one of them, the only one with state participation (UNESA, 2004).

Also in 1991 a new energy national plan was approved, PEN 91, expected to be valid until 2000. The plan had four main goals: to minimize cost, to increase the use of national resources, to protect the environment and to diversify fuels (UNESA, 2004). However, in 1995 the government admitted that the demand forecasts were too high in comparison with the real demand, and released a revision of the PEN-91 (Mir, 1999).

In 1994 the Special Regime is defined, with foundations in the law for Conservation of Energy from 1980 (see 4.5.1). The following installations were defined as Special Regime:

- Hydropower up to 50 MW of installed capacity.
- Cogeneration
- Energy from waste
- Biomass
- Renewable energy (new plants)
- Plants that use heat recovery

Distributers are forced to buy electricity from those types of power plants if they had less than 100 MW, except from hydropower where the limit is 50 MW (CNE, 2010).

4.6.2 Electrical system in Aragón

With the new reorganization, classification of main producers and distributers companies lost its importance. The main group operating in Aragón was ENDESA, but the previously existing self-producers remained. There were three companies distributing energy in Aragón during this period: ERZ, ENHER (both in the Endesa group) and Electra del Maestrazgo (Aragón, 2000).

The efforts made by the Spanish government since 1980 to promote cogeneration plants had effect in Aragón. The first cogeneration plant was installed in 1987 to cover the heat demand of a paper factory in Zaragoza. From 1994, when the special regime was introduced, the number of cogeneration plants grew substantially. Biomass was used as fuel in some of the cogeneration plants (Aragón, 2000).

Also in 1987, the first wind farm was installed in Zaragoza. It consisted of 12 windmills with a capacity of 30 kW each. The project was a collaboration between ERZ, ENDESA, the regional government and the Instituto para la Diversificación y Ahorro de la Energía [30] (IDAE) (Aragón, 2000).

Escatrón thermal power plant was closed in 1988. However, as coal deposits in Aragón are considered strategic for Spain, the power plant was open again in 1991 as a demonstration project for fluidized bed combustion. The plant became part of the regulated system in 1996.

The first regional energy plan was made in 1994 by the DGA. The Plan Energético Aragonés[31] 1994-2013 (PEA) could not forecast the changes that occurred in the system, especially regarding the introduction of new technologies (see section 5). Therefore in 2005 the PEA was updated in order to include both changes occurred in the system and the new knowledge.

Figure 11 shows the evolution of installed capacity, electricity generation and electricity consumption in Aragón from 1986 to 1997. Electricity demand grew 4% in yearly average. Installed capacity stayed approximately constant in comparison with previous periods. It increased only 1% yearly average. The growth was mostly due to cogeneration, and wind power from 1995 (for more details see section 5). Aragón continued the exportation of electricity. More than 40% of the electricity produced was exported.

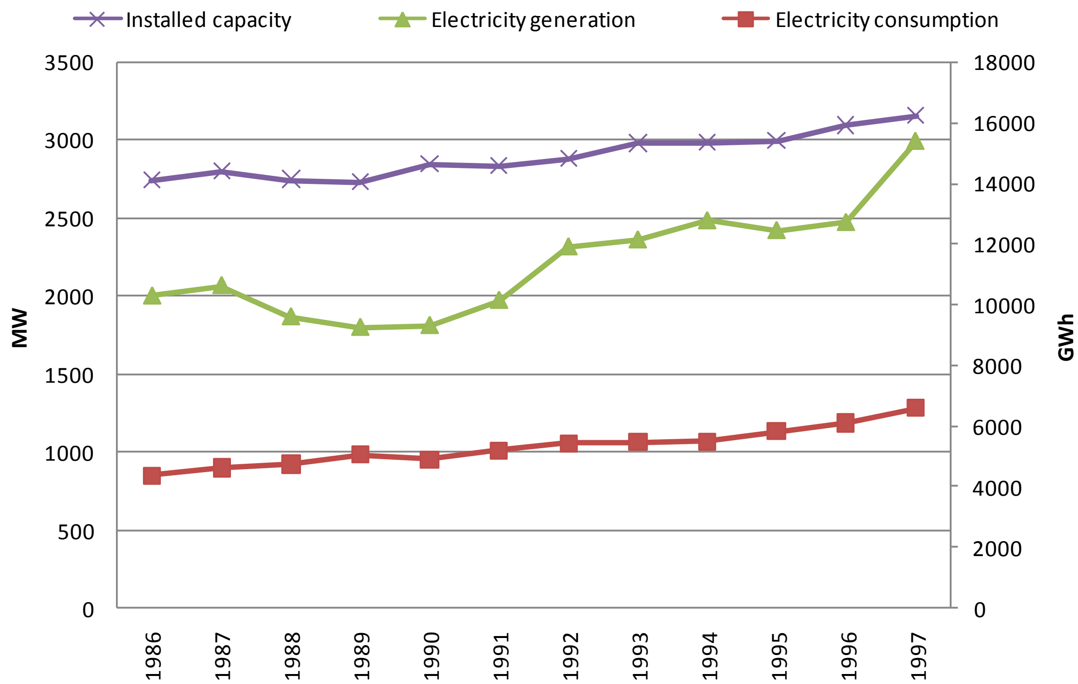

Figure 11 Installed capacity, electricity generation and electricity consumption in Aragón from 1986 to 1997(DGA, 2000,)

[30] Institute for Diversification and Savings of Energy
[31] Energy Plan of Aragón

4.7 Liberalization of the electric sector and new technologies (1998-2008)

4.7.1 Spanish electrical system

Laws regulating the electrical system changed in 1997 to carry on the liberalization, and so did the traditional roll of the state planning. Now each company will decide what to install, while the government can only decide about transmission lines and administrative issues. There is also freedom to buy and sell electricity in other EU countries, as well as to access transmission and distribution grids. Besides, from 2003 each consumer has the right to decide supplier. Endesa and REE became private companies (UNESA, 2004). As a result, the sector was divided in two:

- Regulated activities: transmission and distribution
- Not regulated activities: generation and commercialization.

Under this new regulation, supply and demand are balanced daily. Each power plant informs about the quantity and price of electricity that is planning to generate every hour of the following day. Then REE balances demand and generation according to prices. The price of electricity is the price of generation of the last plant needed to cover the demand (UNESA, 2004).

At the beginning, electricity tariffs were equal in the whole country, except for "qualified consumers" that could negotiate their contracts. The government could revise and change the average tariff annually or when considered necessary. From 1st of July 2009, tariffs have undergone a major change: the regulated tariffs have disappeared. Instead, the consumers now have two choices (B.O.E, 2009):

- Negotiate a price with a commercialization company (this is, become a "qualified consumer")
- Choose the Tarifa de Último Recurso[32] (TUR). The TUR is decided by the government and equal in the whole country. Only consumers with less than 1000 V and 10 kW can choose this option.

Spain has become leader in renewable energy during the last years. Government support with feed-in tariffs has played a major role is this process (del Río González, 2008, del Río and Unruh, 2007). Feed-in tariffs were introduced in 1998, and improved in 2004 and 2007 (del Río González, 2008). With this system, renewable generators chose between a premium above market price for each kWh generated or a fixed price per kWh.

However, according to the Spanish government, major differences between planned and real installed capacity of solar PV and wind power made it necessary to change the renewable regulation (B.O.E., 2008). Therefore installed capacity caps and new tariffs have been introduced for wind and solar power (I.E.A, 2009). In the opinion of renewable energy producers, changes are damaging the market and Spanish leading position in wind and solar energy (A.P.P.A, 2009).

The most important plan regarding sustainable energy is the Plan de Energias Renovables[33] (PER 2005-2010). The PER 2005-2010 had three main goals by 2010: 12.1% of the total pri-

[32] Last Resort Tariff
[33] Renewable Energy Plan

mary energy consumption will be supplied by renewable sources, as well as 30.3% of the electricity demand, and biofuels will be 5.38% of the total fuel use in transport (B.O.E., 2008).

At the same time as renewable technologies have developed, combined cycle using natural gas has become the most important technology in Spain. According to the DGA, one of the major concerns is the high energy intensity, both in Spain and Aragón. Combined cycle has a better efficiency than traditional coal power plants, and therefore it is an interesting technology to decrease energy intensity. (DGA, 2005a).

4.7.2 Electrical system in Aragón

Figure 12 shows the evolution of installed capacity, electricity generation and electricity consumption in Aragón from 1998 to 2008. Installed capacity increased 8% in yearly average. Wind power installed capacity increased during all the period, while the highest increase from 2006 is due to CC (for more details see section 5). Electricity demand grew 5% in yearly average. More than 50% of the electricity produced was exported.

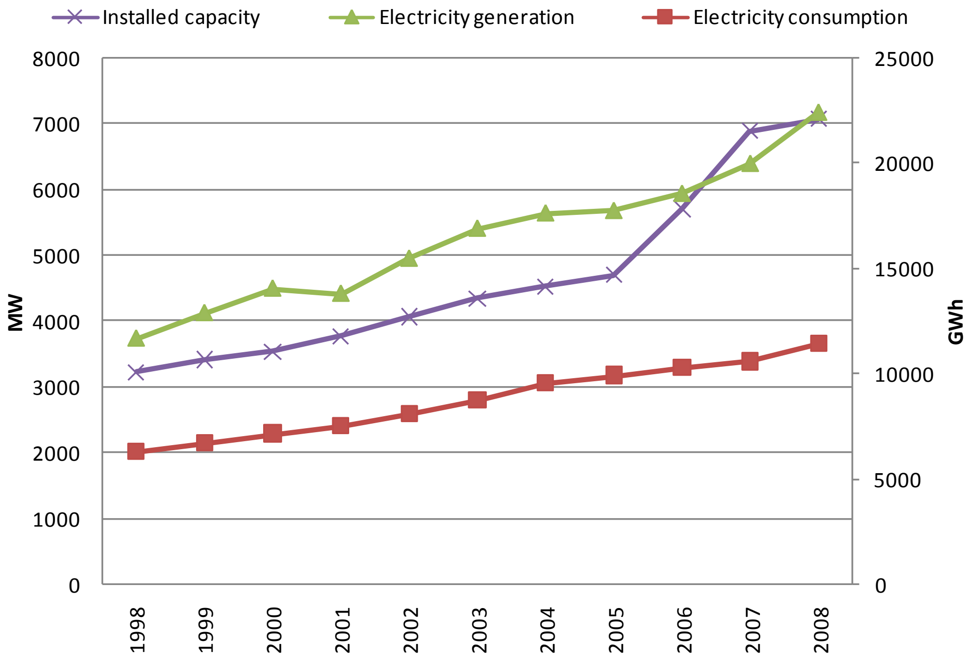

Figure 12 *Installed capacity, electricity generation and electricity consumption in Aragón from 1998 to 2008. Source: (DGA, 2000, DGA, 2005a, Ministerio de Industria, 2010, DGA, 2006, DGA, 2007, DGA, 2008) (DGA, 2009c)*

In 2008 he most important electrical utilities in Aragón were Endesa, Iberdrola and E.ON (DGA, 2009c). Endesa is the owner of most of the hydropower plants, and also of the C.T. Teruel (Endesa, 2001a). Iberdrola is the leader in Aragón in wind power with 262 MW of installed capacity and also owns some hydropower plants (Iberdrola Renovables, 2010, Iberdrola, 2010). E.ON has also wind power farms, a total of 125 MW in Zaragoza. E.ON operates Escucha coal thermal power plant and Escatrón CC power plant (Eon AG, 2010). On the distribution side, Endesa covers most of the Aragonese territory (Endesa, 2001b). Only a small part of Teruel has service form the valencian company Electra del Maestrazgo (Electra del Maestrazgo, 2006).

5 Electricity generation from 1992 to 2008

5.1 Technologies used to generate electricity

From 1992 to 2008 there are six technologies that generate electricity: coal thermal power plants, hydropower, cogeneration, wind power, combined cycle and solar PV. In this section the evolution of these technologies is explained in detail from year 1992 to 2008. Year 1992 was chosen as a starting point because it was the first year in which heat from cogeneration and different renewable energy sources were included as separated data.

Figure 13 shows the evolution of installed capacity for the different generation technologies. Coal and hydro power installed capacity has remained approximately constant, with small fluctuations due to maintenance. The technology with the most marked change is CC. The first power plant started operation in 2006 with 791MW. In 2008, CC is the technology with the highest installed capacity, 25% of the total.

Installed capacity of wind power has continuously increased, reaching 1,712 MW in 2008. There are three reasons for this increase: feed-in tariffs, development of the technology, and excellent wind conditions (DGA, 2005a). However, during last years, growth has decreased reaching almost 0% in 2008. This is because of problems that wind technology has, in Aragón mainly lack of transmission capacity of existing electrical grids. Another reason is that the best locations to place wind farms are already occupied (DGA, 2005b). These could mean that the market is starting to show signs of saturation.

Cogeneration has grown continuously, but not as expected in the regional plants. The reason for this was the uncertainty in fuel prices and the changing prerequisites necessary to install a cogeneration facility (DGA, 2005a).

Solar PV is the technology with less installed capacity, although it has grown continuously since 1997 and it multiplied by more than 18 in 2008. As for wind power, feed-in tariffs and technology development are the most probable causes for this evolution.

Electricity generation by technologies is shown in Figure 14. Both coal thermal and hydropower electricity generation fluctuate, but with and approximately constant trend. Historically, more coal is used in dry years, although the fluctuations are more dependent on national strategy regarding coal and water reserves than on weather conditions. However, coal thermal seems to follow a decreasing trend in generation since 2005. Data for year 2009 in Aragón is still not available, but there is information indicating that coal thermal generation has decreased to a minimum after 2008 (REE, 2009).

Cogeneration, wind power and combined cycle together represent around 60% of the electricity produced in Aragón in 2008. Electricity generated by cogeneration had increased together with installed capacity. Cogeneration also generates 4,187 GWh of heat, more than 99% of the final heat final demand in Aragón (note the difference between final heat demand and useful heat demand). Regarding wind power, the technology had a negligible share in generation capacity in 1992, while in 2008 it generates around 18% of the electricity in the region. CC is the technology that generates the most electricity, which in 2008 represents 26% of the electricity generated in Aragón.

Finally, solar PV share in electricity generation is still less than 1%. However, electricity generated from solar PV has growth 51% in average every year, except from year 2007 to 2008, when solar PV electricity generation increased from 5 GWh to 122 GWh.

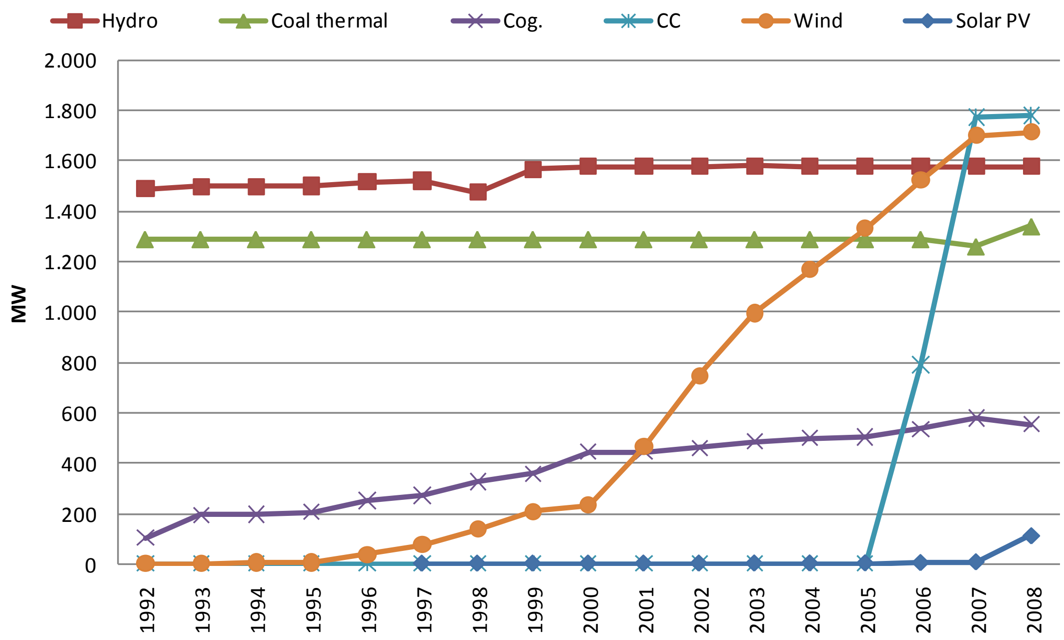

Figure 13 *Installed capacity for the different generation technologies from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

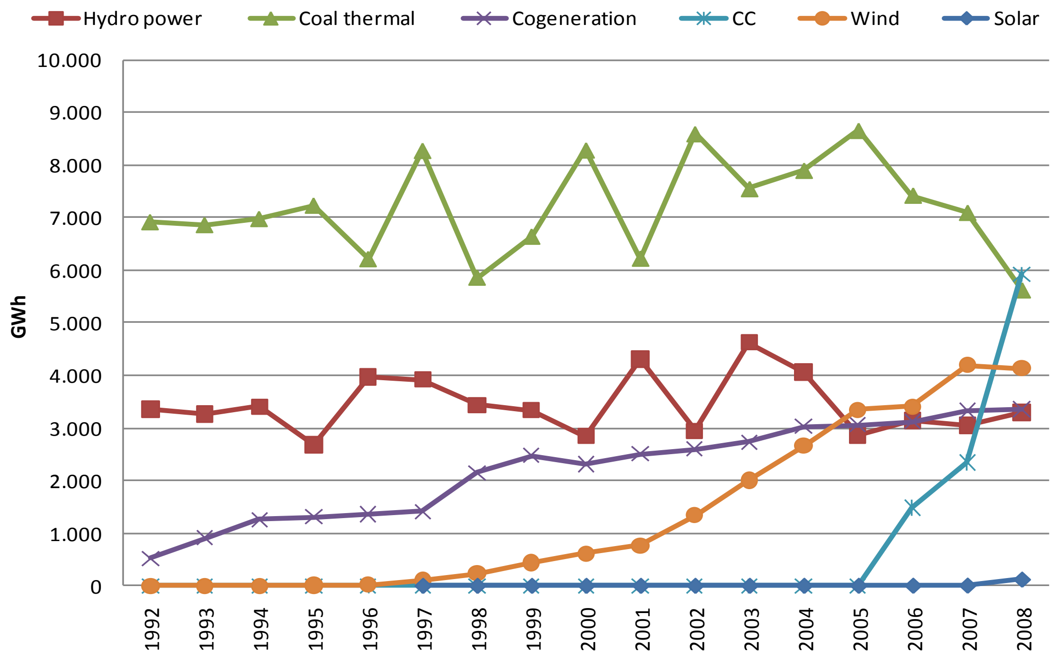

Figure 14 *Electricity generation by technology from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

Figure 15 shows the equivalent working hours for each technology, calculated as in equation (1). The result gives the number of hours that the power plants would work in maximum capacity to generate the amount of electricity that each technology has generated during one year. The maximum equivalent working hours are 8760, which means that the power plants have been working at maximum capacity the whole year. Thus, the value gives some guidance about how much of the installed capacity is actually used for each technology.

$$\boldsymbol{h}_{eq} = \frac{Electricity\ generation\ [MW\boldsymbol{h}]}{Installed\ capacity\ [MW]} \qquad (1)$$

The first characteristic of Figure 15 is the difference in working hours between coal thermal and cogeneration and the rest of the technologies. The reason for this is that renewable technologies are dependent on the availability of the resource, and therefore they would work only during the hours that the resource is available. This leads to an important difference between generation technologies: wind power and solar energy cannot be managed as coal thermal, cogeneration or CC. Hydropower can be regulated as coal thermal and CC as long as water is available. In the case of CC the reason to have less working hours than expected is that there is no need of using all the installed capacity.

All technologies have an approximately constant value of their equivalent hours during the period. Deviations are found in wind power, CC and coal thermal. Deviations in wind power in 1994 and 1996 are caused by installation of new wind farms that could not work at full capacity during the first year. Regarding coal thermal, the equivalent working hours have decrease since CC was introduced in Aragón. The effect is stronger during 2008, when CC increased its working hours.

5.2 Fuel used to generate electricity

Only coal thermal power plants and cogeneration facilities use more than one fuel. The rest of the technologies use the corresponding renewable resource, or natural gas in the case of CC.

Coal thermal power plants use both local coal and imported coal, since local coal has high sulphur content and low energy content. The amount of coal imported that is used depends on national strategies and prices, and during these years it has been between 15% and 61%. A higher percentage of imported coal is used when electricity generation in coal thermal power plants is higher. Coal power plants also consume small amounts of diesel and natural gas for start-up.

Cogeneration is the other technology that also uses more than one fuel. Figure 16 shows the evolution in the use of different fuels in cogeneration facilities. Natural gas is the most used fuel and it has increased in more than 7,000 GWh from 1992. The second most important fuel is biomass. Biomass utilization in cogeneration had and important growth from 145 GWh in 1997 to 1,095 GWh in 1999. From 1999 the use of biomass is approximately constant. Oil products (fuel oil and diesel) started to be used in year 1996. Their contribution peaked in 1999 with 400 GWh, and after that their utilization has decreased to 101 GWh in 2008. Finally, there is a very small amount of waste products used in cogeneration plants, 17 GWh in 2008.

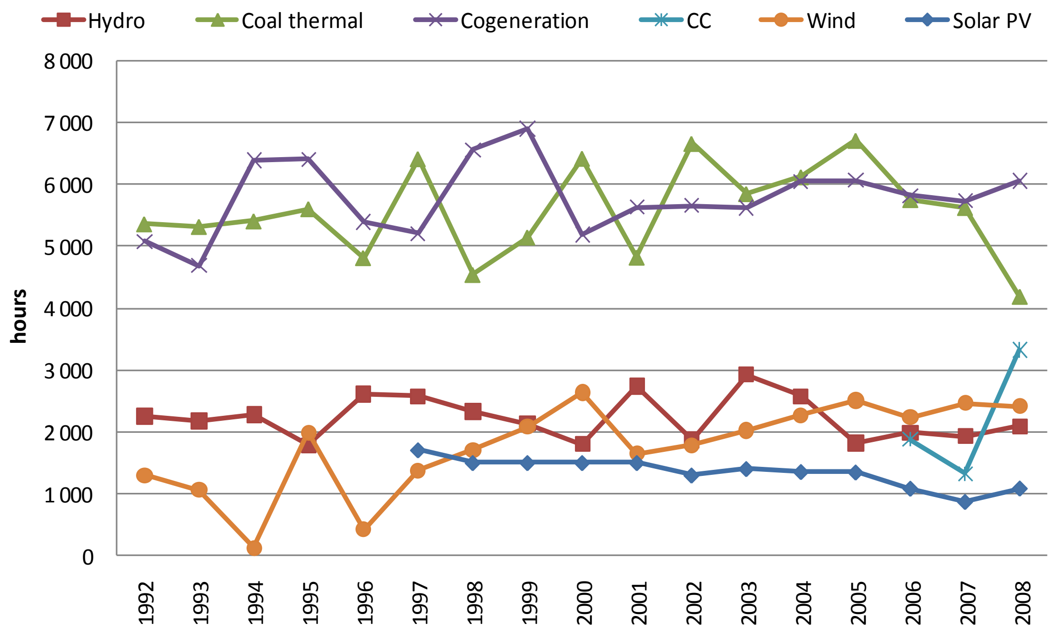

Figure 15 *Equivalent working hours for each technology from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

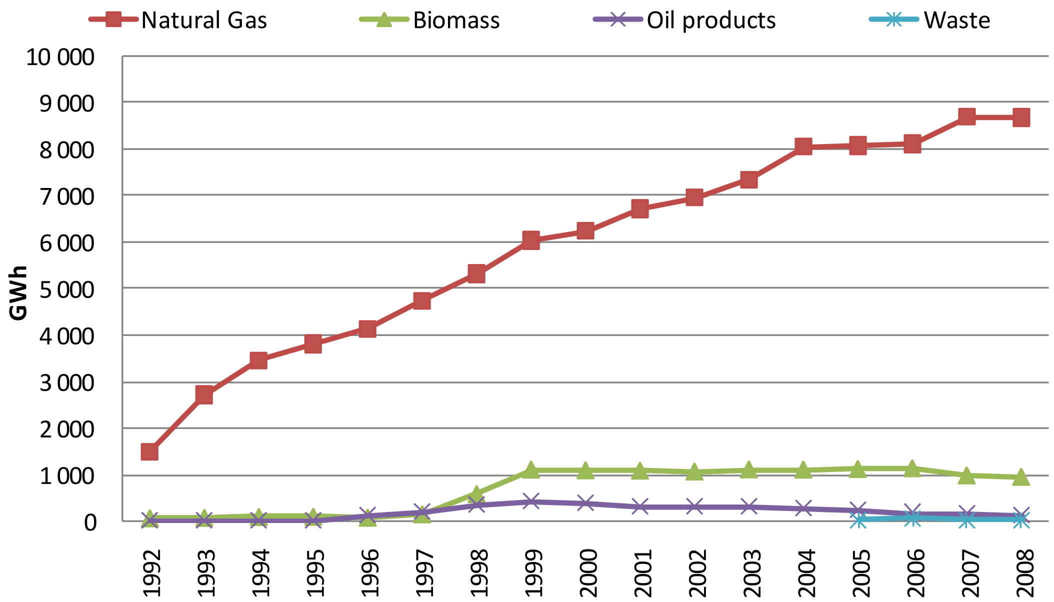

Figure 16 *Fuels in cogeneration facilities. Oil products include fuel oil and diesel. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

6 Energy system development from 1992 to 2008

Evolution from year 1992 is described in this section, focusing in year 2008 since it is the base year for calculations in LEAP. Year 1992 was chosen as a starting point because it was the first year in which heat from cogeneration and renewable energy were included as separate data.

Notice that oil products, hydrogen and biofuels are included as primary energy and called energy inputs in order to have the same criteria as the DGA. Besides, the main changes are in the electricity generation, which have been explained in Sections 4 and 5.

During this period Aragón, and Spain, underwent an important economic growth. Population has also grown, especially from 2002 (IAEST, 2010b). Therefore energy consumption has increase both in Aragón and Spain.

For more detailed data about the entire energy sector in year 2008 see the energy balance in Section 9 Figure 31.

6.1 Energy inputs

Energy inputs are divided in imports and regional production. Imports include all oil products, biodiesel, natural gas, coal (anthracite) and other fuels (used oils and waste). Regional production includes coal (lignite), biodiesel, hydro, wind, biomass, solar, hydrogen and geothermal. The only energy form that is exported is electricity.

Evolution of total energy inputs, exports, production and electricity exports are represented in Figure 17. Consumption and imports of energy inputs grow 2,371 ktoe and 2,385 ktoe respectively. This represents 58% more consumption and 91% more imports in 2008 than in 1992. On the other hand, production of energy inputs increases only in 249 ktoe, or 15%, during this period. This is explained because imported products dominate the energy inputs in Aragón. Electricity exports have undergone a 95% increase during these years

Figure 18 shows the energy inputs in Aragón by sources from 1992 to 2008. The three most important energy inputs are oil products, natural gas and coal. The most important change is the increase of 1,942 ktoe in natural gas consumption during this period. This is due to the development of the infrastructure, the easier use, and the better efficiency of the technologies that use natural gas. It has also substituted other fuels especially in the industrial sector (DGA, 2005a).

During this period the used of oil products has increased in 559 ktoe. Oil products are important in Aragón because of high traffic density due to its location between the most important industrial areas in Spain.

Coal consumption fluctuates, although the trend seems to be a decrease, especially from 2005. The difference between the consumption in 2008 and 1992 is 654 ktoe. In Aragón coal is mainly used to produce electricity, which can be noticed looking that Figure 14 and Figure 18 together.

The rest of the energy inputs sources have not undergone any important change, apart from wind. This changed is already explained in Section 5.

Figure 19 sums up the situation of the energy inputs consumption in Aragón in 2008. One of the important characteristics of the energy sector in Aragón is the high share of renewable sources. They represent 14.9% of the primary consumption, which fulfils the European target of 12% for 2010 (European Parliament, 2001).

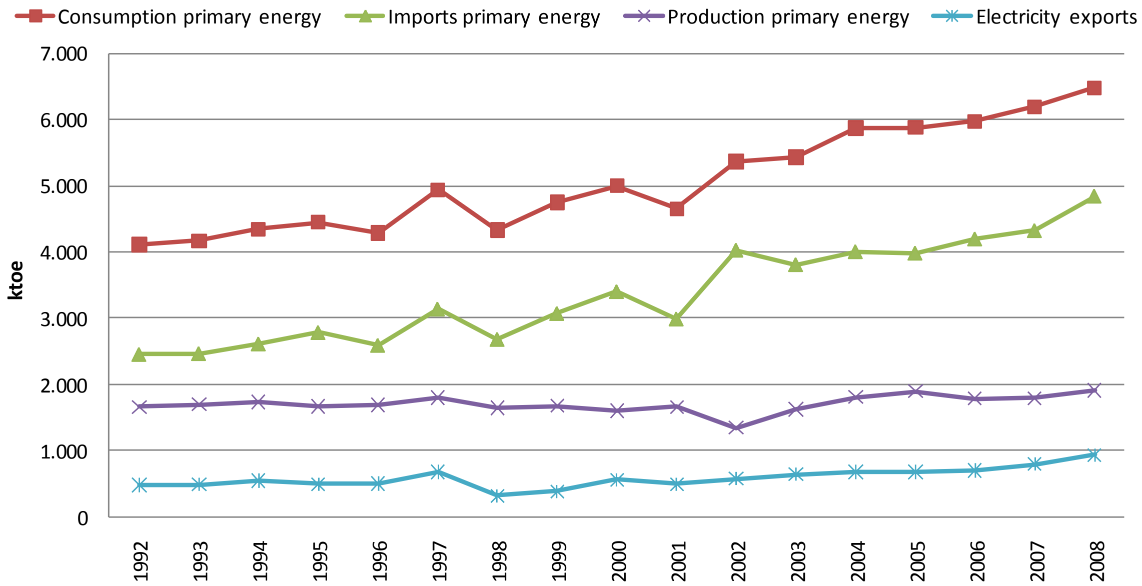

Figure 17 *Evolution of the consumption of energy inputs, imports, production and exports of electricity from 1992 to 2008 in Aragón. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

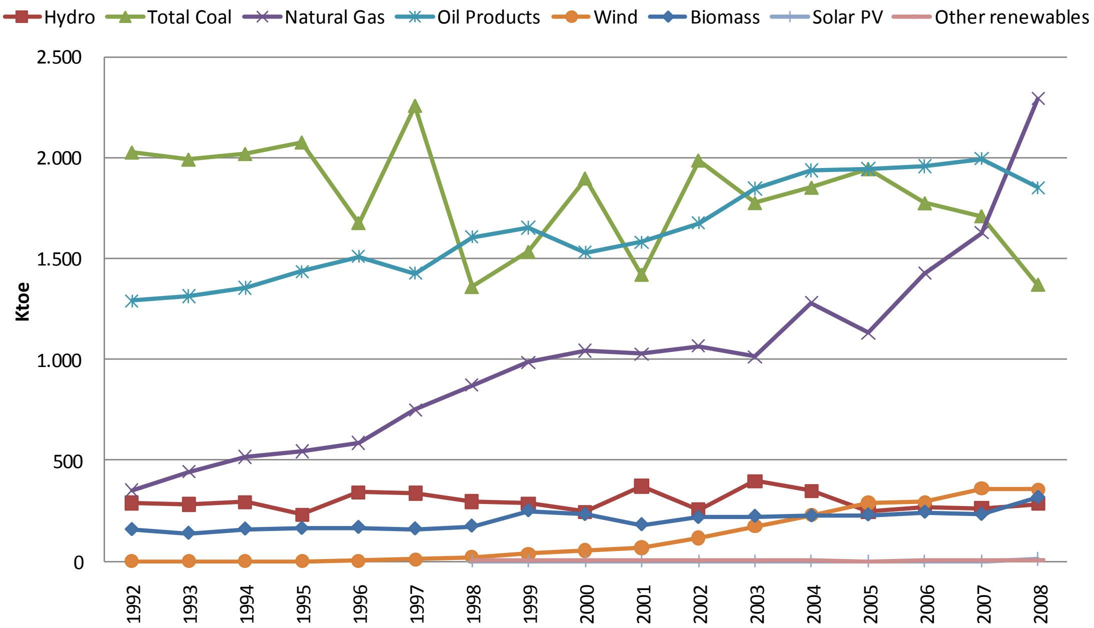

Figure 18 *Energy inputs consumption from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)*

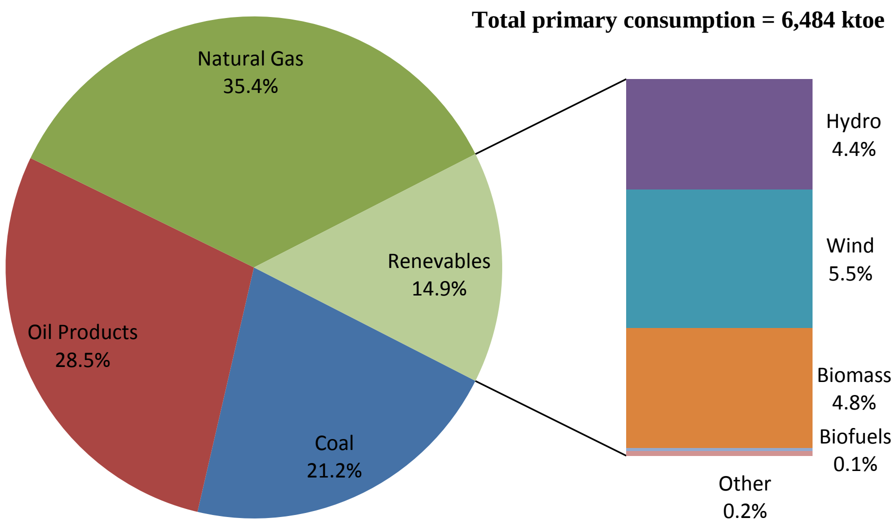

Figure 19. Energy inputs consumption by sources in Aragón in 2008. Other includes geothermal and solar. Source (DGA, 2009b, DGA, 2009c)

6.2 Transformation

Electricity generation evolution is analysed in Sections 4 and 5. Thus only heat generation is explained here.

Heat is only produced in Aragón by cogeneration plants, solar thermal and geothermal. Cogeneration plants evolution has been explained with electricity generation in Section 5. The share of geothermal and solar thermal is insignificant, with less than 0.5% each.

Heat is mainly used by the industry sector, since there is no district heating network in Spain. Each cogeneration plant delivers heat to one industry, and must be design according to the amount of heat needed (DGA, 2000). Heat demand in households is mostly met by natural gas or oil product boilers. That heat is useful energy (not final energy). Thus, fuel used to obtain useful heat is included in final energy statistics, but not as heat itself.

Losses in electricity transmission are estimated by the DGA as 2% (DGA, 2009a). Data for the rest of the fuels was not found.

6.3 Final energy

There is an overall increase of demand due to economic growth, from 2,211 toe in 1992 to 3,989 toe in 2008. Figure 20 shows the evolution of the fuels final demand in Aragón from 1992 to 2008, and Figure 21 the situation in 2008.

Oil products are the most used fuels used. Although consumption of oil products increases steadily, their share in the total final consumption decreases from 60% in 1992 to 46% in 2008.

The second most used energy carrier during these years is electricity. Consumption of electricity has increased 110% from 1992. Electricity accounted for 21% of the final energy consumption in 1992, while in 2008 its contribution was 25%.

Natural gas is the third most used fuel. The use of natural gas has multiplied by 1.7 during this period. Its relative importance in the final fuel mix increased from 9% to 13%. This increase in use has been possible due to infrastructure development.

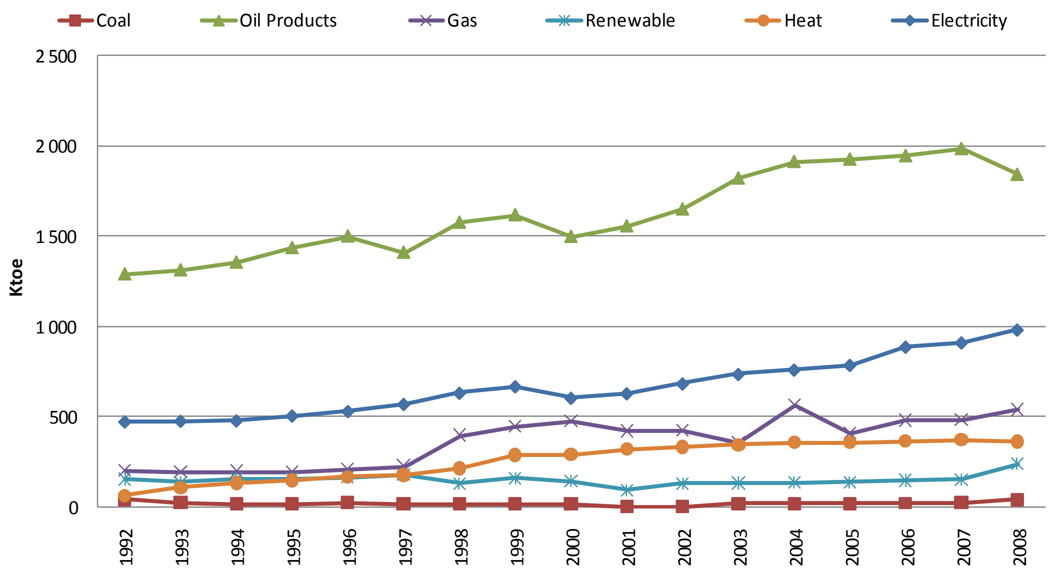

Figure 20. Final energy consumption by sources from 1992 to 2008. Source: own elaboration from (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)

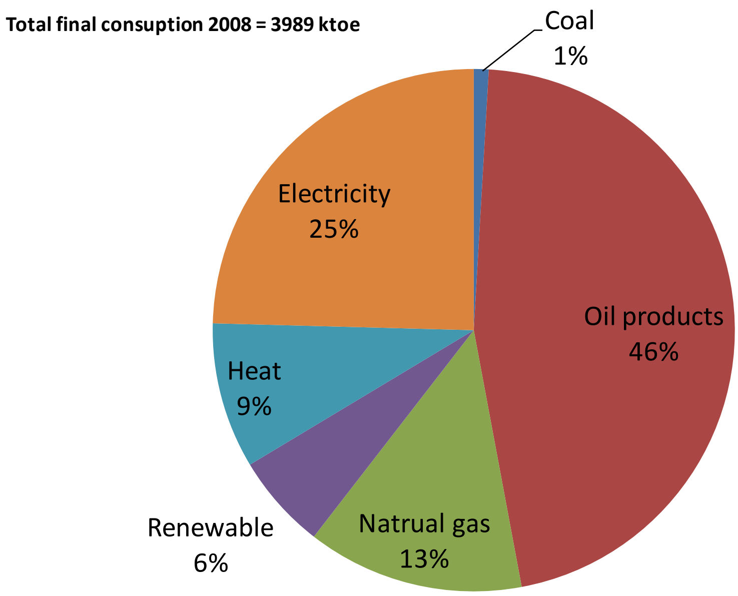

Figure 21 Final energy consumption in Aragón in 2008. Source: (DGA, 2009a)

Heat demand underwent the most important relative growth, multiplying by 4.7 in the past sixteen years. In 2008 it represented 9% of the total final demand, while in 1992 it only made 3% of the demand. However, this increase was more important at the beginning of the period. Heat demand evolution is correlated with the explanation for cogeneration plants given in section 5.

Coal and renewable sources final consumption stays constant. However, renewable energy use increased 59% from 2007 to 2008, which in total made the renewable energy use to grow 56% during the period. In year 2008 renewable sources represented 6% of the final energy demand and coal 1%.

Final energy consumption by sectors is shown in Figure 22. Industry and transport are the sectors that consume more energy, both slightly above 30%. Their development trend during this period is also similar. Industry demand has been multiplied by 2 while transport by 1.7 from 1992 to 2008.

Energy demand in the Residencial, Service and Comerce sector (RSC sector) has been multiplied by 1.4. While in 1992 RSC demand represented around 25%, in 2008 it was 20%.

Finaly, agricultural sector has the mayor relative increase; it has multiplied its consumption by 3. Agricultural sector share was 5% in 1992 and 10% in 2008. However, there seems to be a breaking point of the trend in 2004, since the energy consumption has decrease since then.

Fuel share by sector in year 2008 is shown in Figure 23. Electricity and natural gas dominate in both RCS and Industrial sectors, while diesel is the most important fuel in the agricultural and transport sector.

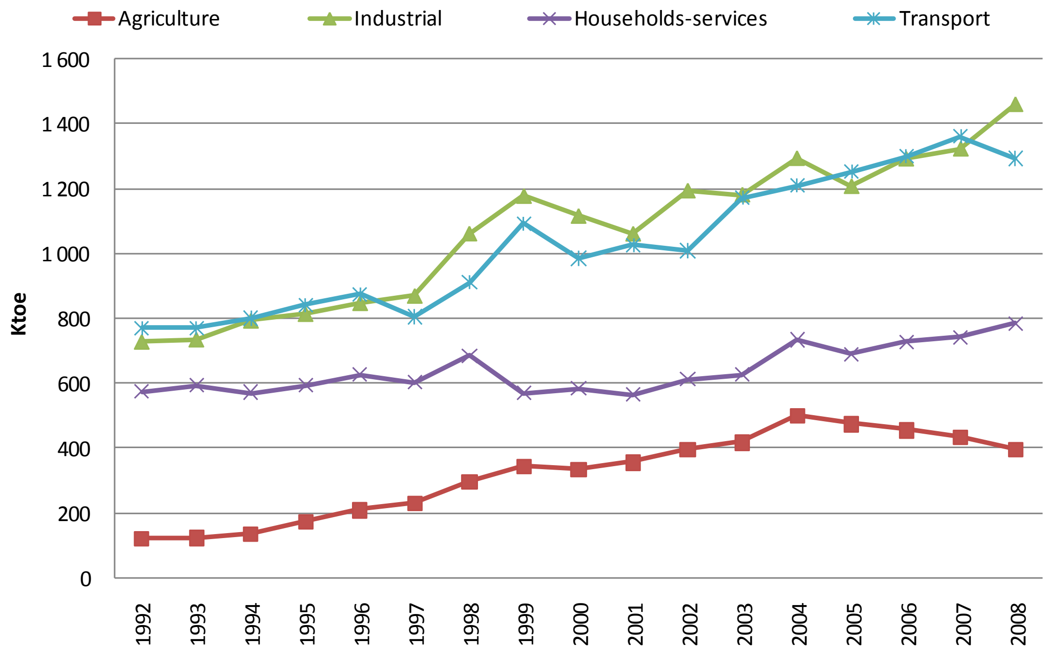

Figure 22 Final energy consumption by sectors from 1992 to 2008. Source: own elaboration from (DGA, 2000), (DGA, 2005a),(DGA, 2006, DGA, 2007a, DGA, 2008, DGA, 2009c)

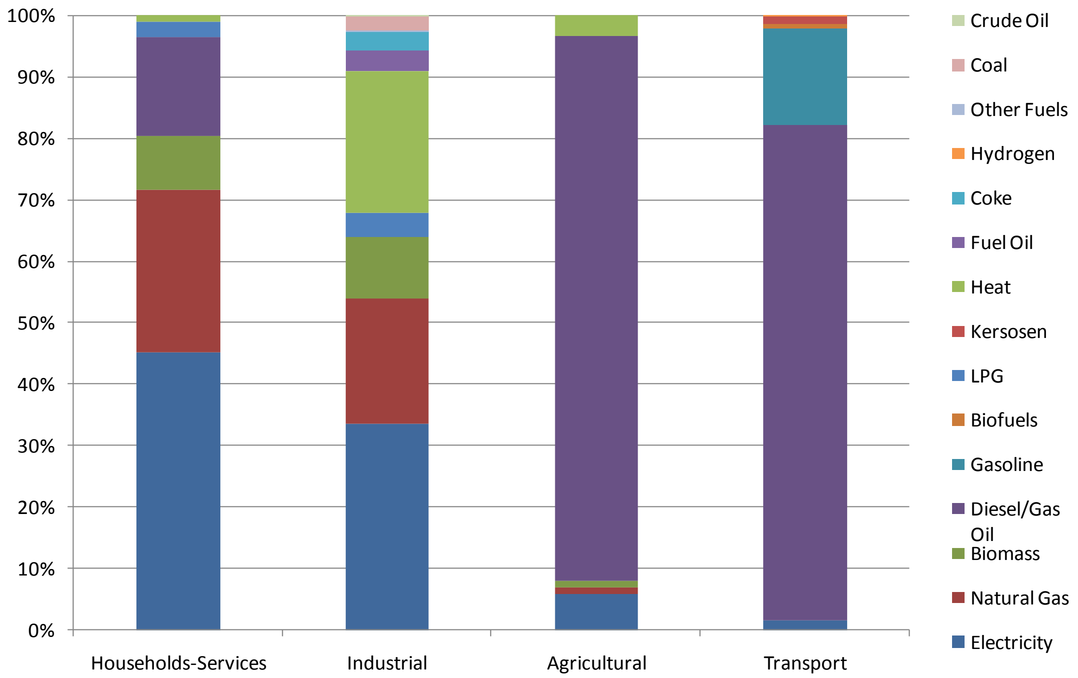

Figure 23. Fuel consumption share by sector in 2008. Other fuels include waste and recycled oils. Source: (DGA, 2009b, DGA, 2009c).

7 About models

A model is a representation of a system. According to Sterman, a computer model should be documented and open for discussion; it should reflect the logical consequences of the assumptions taken to build the model; and it should be able to deal with relationships between factors. Besides, a model should have an aim, a problem to solve (Sterman, 1985). When studying the energy system, models have been used since the 70's to try to forecast energy offer and demand (Wei et al., 2006).

It is important to be aware of what is the function of systems modeling. In general, and more importantly in this project, the aim it is not to do planning, but education. Moreover, a model should not be considered as a prediction neither be a substitute critical thinking (Sterman, 1985). The function of systems modeling is to improve knowledge about the system, and hopefully this knowledge will help policy makers or other stakeholders to achieve certain goals or make decisions that will improve the system.

There are several classifications of models, being two of the most used top-down versus bottom-up and optimization versus simulation. A top-down model is based on economical parameters and their relation with energy demand and production. Advantages are that data is relatively easy to collect and that macroeconomic effects are reflected. However, the effects of technology development are not reflected in detail, resulting in an underestimation of technology potential. CGE (Computational General Equilibrium Model) is an example of top-down models (Wei et al., 2006). On the other hand, a bottom-up model is built up from data of technologies. Advantages of this type of models are that technology development can be modeled and that they can be used for exploring different technology options. The main drawbacks are the difficulty to collect data and that the results can overestimate technology potential when market constraints are not included. MARKAL (Market Allocation of Technologies Model) is an example of a bottom-up model (Wei et al., 2006). There are also hybrid models, as for example MIDAS, which has been used by the Spanish government for energy planning (Mir, 1999).

According to Sternman, the classification optimization versus simulation is maybe more important because each type solve a different problem. An optimization model provides the best solution to reach a goal, while a simulation model aims to imitate the behavior of the system under study. MARKAL is an example of optimization models, and MIDAS is a simulation model.

The three models in this study can be classified as follows:

- Logistic curve has been used to model electricity demand, installed capacity and electricity generation. The aim was to show a possible development of the system under constant conditions. Thus the logistic curve is a simulation model.
- The second model used was the energy balance model. The energy balance model is a different type of model, since it does not aim to optimize the model or to simulate it. The energy balance aims to describe the state of the system in a given moment. Thus, it could be classified as a descriptive model.
- LEAP has been used to model the energy system in Aragón and build four different scenarios. The model built in LEAP is a bottom-up simulation model.

When doing futures studies, different scenarios can be developed. A scenario is the description of a future state or a development, and can also include sensitivity tests (Börjeson et al., 2006). Börjeson proposes a classification of scenarios with 3 groups: normative, explorative and predictive. Normative scenarios try to show how a goal can be reached. Explorative scenarios are focused in different strategies that the stakeholders should consider. Finally, predictive scenarios try to show how the system will develop. Predictive scenarios are divided in forecast scenarios, which try to show the most likely development, usually in the shot time, and what-if scenarios. A what-if scenario answers the question "what will happen under some specific events?"

Following Börjeson classification, scenarios included in this report are predictive what-if scenarios. Predictive what if scenarios aim to simulate the behavior of the system but do not focus on the most likely development. Thus, this type was considered to have the most suitable characteristics for this project, where the goal is to generate knowledge about the energy system, not to forecast what is going to happen. This study does not define a target that the energy system should reach at the end of the simulation period, thus normative scenarios are not adequate. Explorative scenarios were ruled out because the aim of this study does not include proposing strategies to the stakeholders.

8 Logistic curves

There is empirical evidence that confirms that the development of technologies follows an S-curve, also called logistic curve (Unruh, 2000) [34]. Maldonado used the logistic curve model for energy modeling in Sweden, from which the following introduction to the logistic curve is an excerpt (Maldonado, 1985):

"Forecasting methods have become an integral part of decision making by management. Their range varies from very simple methods to highly complex approaches. Progress in forecasting techniques has increased the degree of sophistication of models used and the introduction of personal computers has made computer programs available for all quantitative forecast techniques and today forecasting models for the simulation of econometric systems or simple economic events, natural phenomena, etc. are available.

In the energy sector there are a great amount of sophisticated models that attempt to explain today´s pattern of consumption. As these models have grown in sophistication, one might expect that the need for "simple" time growth forecasting would have diminished. However, in many computer codes, many of the variables still ultimately depend upon some simple form of time growth forecast.

There is considerable evidence to support the theory that goods and technologies have a finite life. That is, they are introduced, they grow, reach a maturity level, and then decline. This concept can thus be introduced to the study of the evolution of electrical systems, different technologies and appliances using electricity. Growth within energy and electrical power systems can be analyzed in general or by the type of branch or consumers and its appliances and their saturation in each consumption sector. Branches normally are replaced by new technologies or modern equipment, which follow the logistic grow curve.

Using quantitative methods, some form of curve fitting is usually based in historical data. One of the most common curves is the S-curve. In general this curve has illustrated the growth of "populations" (cell, human populations, telephone subscribers, electricity consumption, etc.). Normally, the curve has been used to describe the product life cycle, but its increasing application in other areas, even energy, show that there are a great number of technologies that followed the logistic curve"

Figure 24 shows a typical S curve, which is defined by the differential equation (2):

$$\frac{1}{y}\frac{dy}{dx} = b(a - y) \qquad if\ a > y \tag{2}$$

Where a and b and constants, with a being the asymptote when $x \to \infty$ (Maldonado, 1985).

The objective of using the logistic curve is to show and compare the results of a simple forecast model and a more complex as it is LEAP (see Chapter 16). The logistic curve has been used to forecast electricity consumption, for example in New Zealand. In this case, it was concluded that the forecasts made by the logistic curve where adequate and comparable with other types of forecast using economic data (Mohamed and Bodger, 2003). Besides, the logistic curve is also useful to build the future scenarios. New technologies, such as solar PV or

[34] For different examples of technology evolution studies and logistic curves, see the book *Technology and Global Change*, written by Arnulf Grübler.

electric cars, will emerge in the next decades in order to decrease the CO_2 emissions, and they will evolve following the S-curve.

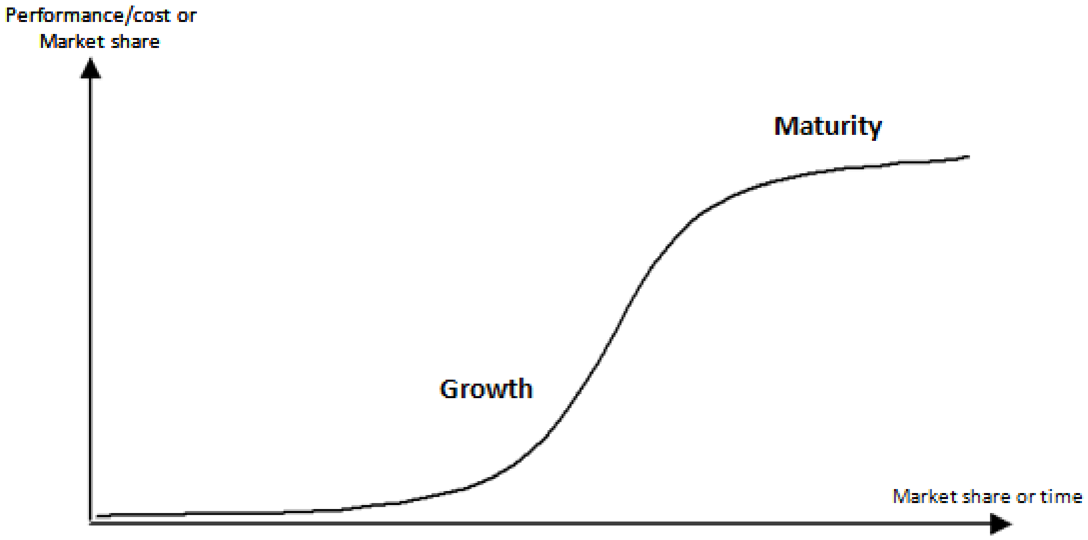

Figure 24 Logistic curve. Source: Modified from Understanding the carbon lock-in (Unruh, 2000)

As Figure 24 shows, the S curve can represent a number of different measurements in each axis. In this study the logistic curves will represent time in the X axis and market share in the Y axis. Examples of market share measurements are installed capacity for electricity generation, number of cars that use biofuels or KWh consumed.

When technologies follow an S-curve it means that in the first stages of the technology development, when it is new or it has not a big market share, positive feedback dominates. Positive feedback means that a bigger market share will increase the relationship performance vs. cost (better performance, lower cost, or both), and therefore the market share will increase, and so on. This results in exponential growth. After some time, when the market share is bigger, negative feedback becomes dominant. Negative feedback causes that when the market share or time increase, the relationships performance vs. cost increase slowly or it stays constant. Therefore market share decelerates or stay constant. (Unruh, 2000). In this situation, technology has reached maturity.

One of the most important characteristics of the logistic curve is that it assumes that the conditions of the system do not change. For example, in the case of electricity generation, when a new technology is introduced in the mix, the logistic curve changes because the system has been changed.

8.1 Method

The logistic curve was the first model used. Historical data was used as input for the program that calculated the logistic curves

The logistic curve was calculated for electricity demand, installed capacity and electricity generation in Aragón. A computer program provided by Chalmers University was used[35].

[35] Further information about the logistic curve and the program used to calculate it can be obtained from Maldonado upon request.

First, the program is run without restrictions, giving as a result future growth and asymptote value. Once the asymptote had been calculated, the same calculation was carried out with +5% and -5% the first calculated asymptote value. Thus a more probable range of growth is obtained.

The logistic curve was also calculated using average percentage grow every three years. The asymptote value obtained is the average growth that the system would have when maturity is reached.

8.2 Logistic curve for electricity consumption

Figure 25 shows the electricity consumption in Aragón from 1959 and the calculated logistic curves. The asymptote for the logistic curve is 25,632 GWh. Electricity demand is still in the growth part of the logistic curve according to this method. Therefore demand will grow 62% from 11,401 GWh in 2008 to 18,493 GWh in 2030. When the asymptote is 5% higher, the consumption in 2030 is 18,943 GWh, 2% higher. If the asymptote is 5% lower, the consumption is 18,016 GWh, 2.5% lower.

In Figure 26 the average percentage growth for every 3 years is represented, together with the calculated logistic curve. The calculated asymptote for the mature system is 1.4%. Currently the growth percentage for every 3 years is between 4% and 5%.

8.3 Logistic curve for installed capacity

Figure 27 shows the evolution of the installed capacity and the calculated logistic curves. Installed capacity is closer to maturity than electricity consumption. The calculated asymptote for installed capacity in Aragón is 11,562 MW, with a value in 2008 of 7,080 MW and a predicted value in 2030 of 9,185 MW. This is a 30% growth during this period. The calculations with ±5% asymptote values give for 2030 a higher limit of 9,697 MW and a lower limit of 9,101 MW. This is a range of ±3% in 2030.

Average percentage growth for every 3 years and its logistic curve is shown in Figure *28*. The calculated asymptote for the mature system is 2%.

It is important to notice that this calculations change when a new technology is introduced. Electricity generation is a mix of different technologies, each of them with a different degree of maturity. When a new technology is added to the mix of existing technologies, it has more potential to grow than technologies that already are mature. Therefore the overall logistic curve for the electricity generation capacity will also increase its potential to grow. In the energy system in Aragón, last technology introduced has had a high impact. If the logistic curve for the installed capacity is calculated from 2005, before CC was introduced, the asymptote changes from 11,562 MW to 5,089 MW.

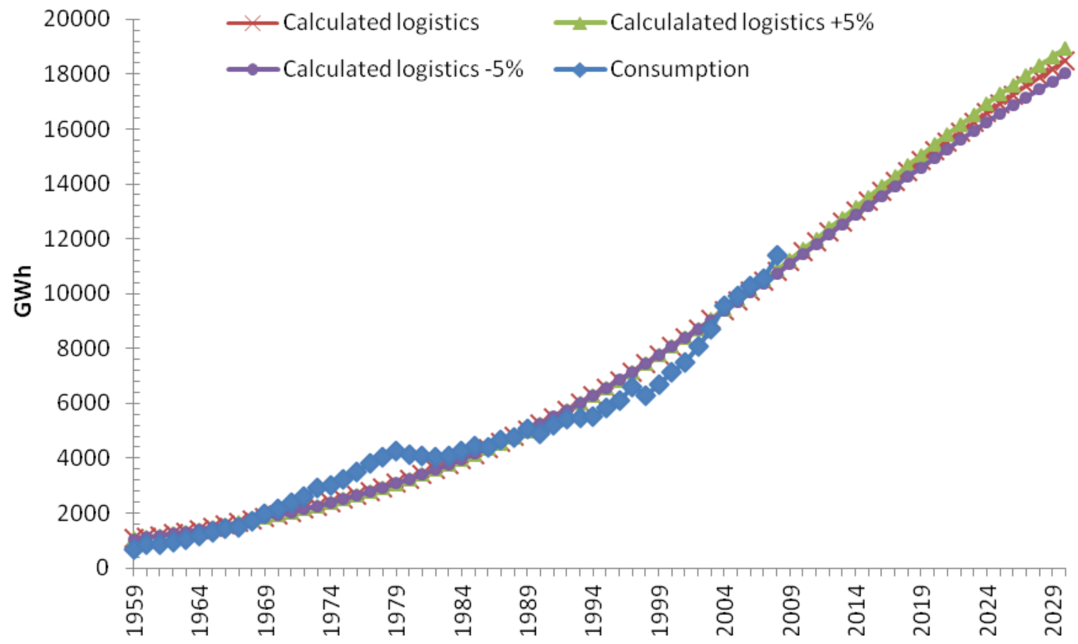

Figure 25 Electricity consumption from 1959 to 2008 and logistic curve until 2030.

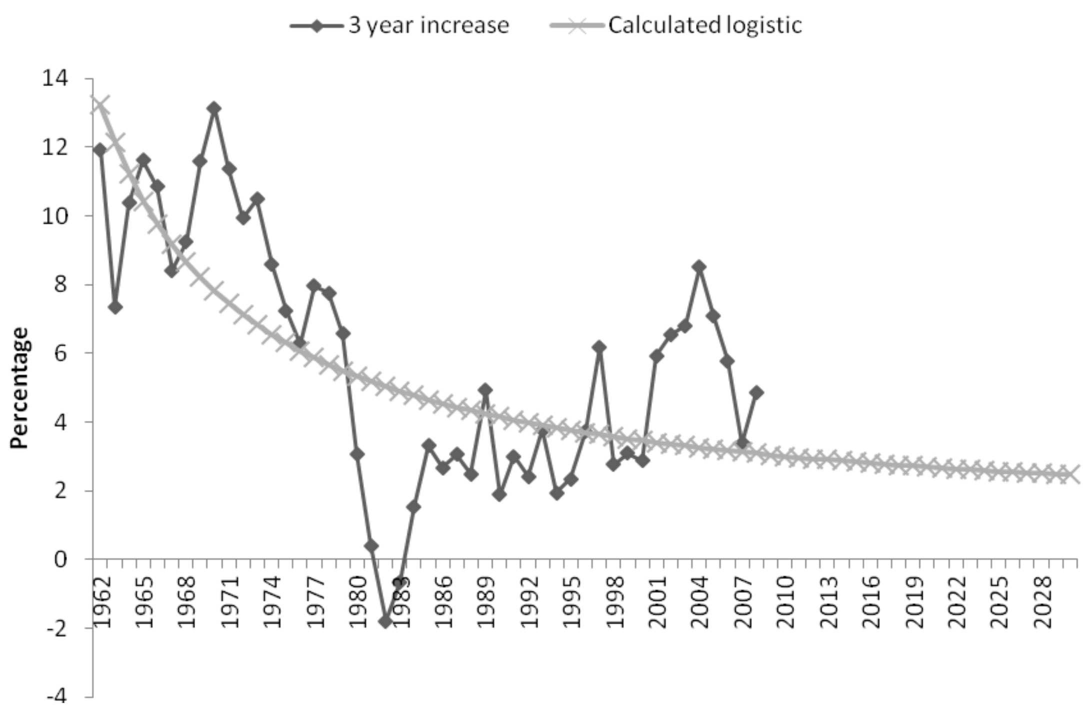

Figure 26 Three year average percentage increase of electricity consumption from 1959 to 2008 and logistic curve until 2025.

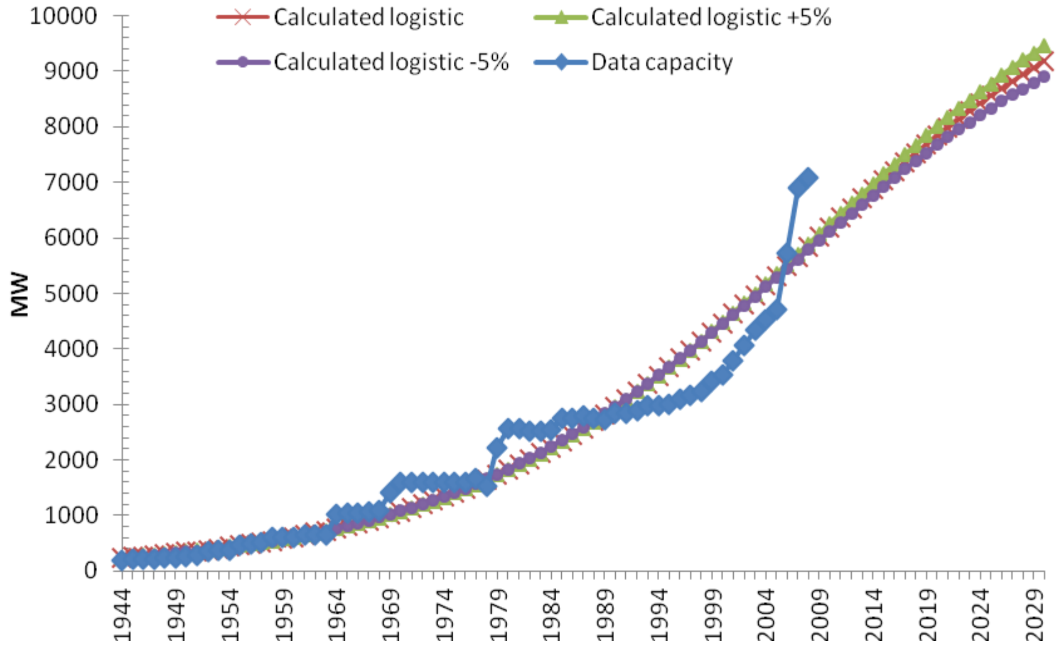

Figure 27 Installed capacity evolution from 1944 to 2008 and logistic curve until 2030.

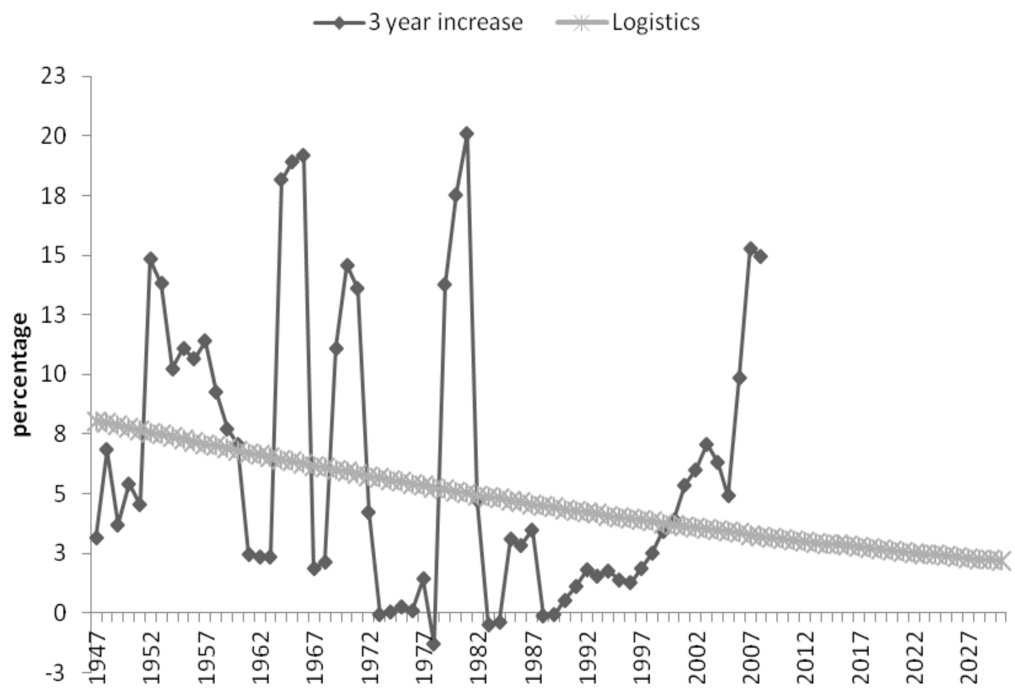

Figure 28 Three years average percentage increase of installed capacity from 1944 to 2008 and logistic curve to 2030.

8.4 Logistic curve for electricity generation

Electricity generation in Aragón has reached the maturity area in the logistic curve, as Figure 29 shows. The electricity produced in 2008 was 22,450 GWh, and the calculated asymptote is 23,871 GWh, only 6% higher.

As for installed capacity curves (see 8.3), generation curves are also affected by new technologies. However, CC has less effect in electricity generation than in installed capacity. The asymptote value changes from 23,871 GWh to 18,564 GWh when the calculations only include data until 2005 (with no CC). This represents "only" a 22% difference, compare to more than 50% difference in the installed capacity asymptote.

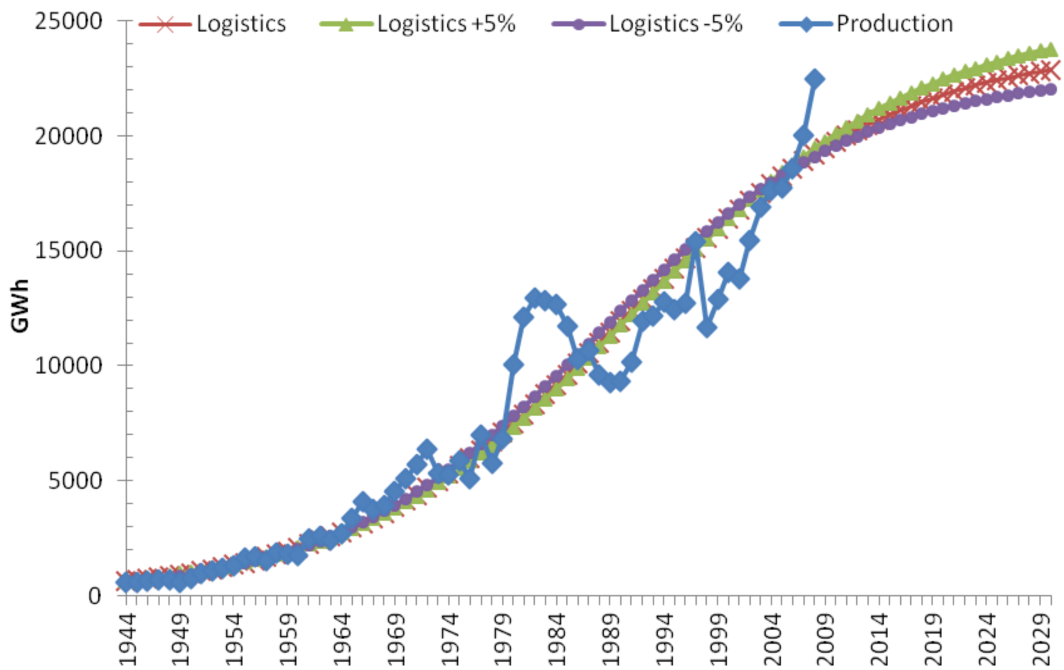

Figure 29 Electricity generation evolution from year 1944 to 2008 and logistic curve to 2030.

9 Energy balance

The energy balance is a good tool in energy studies and planning. It gives an image of the physical relationship of the energy system during a period of time, usually one year. (Vernet, 1983).

The energy balance is a matrix as the represented in ***Figure 30*** (Maldonado, G. 2010). “It is a group of equilibrium relationships that numerically express the physical flow in the energy system in a particular historical period. The general presentation of the energy balance-sheet, where a clear presentation of how the energy sources are produced, exported or imported, transformed, and consumed by each economic activity”.

From the Energy balance-sheet (see) the energy balance- flow is constructed as in the following section. (Maldonado, G., 2010)

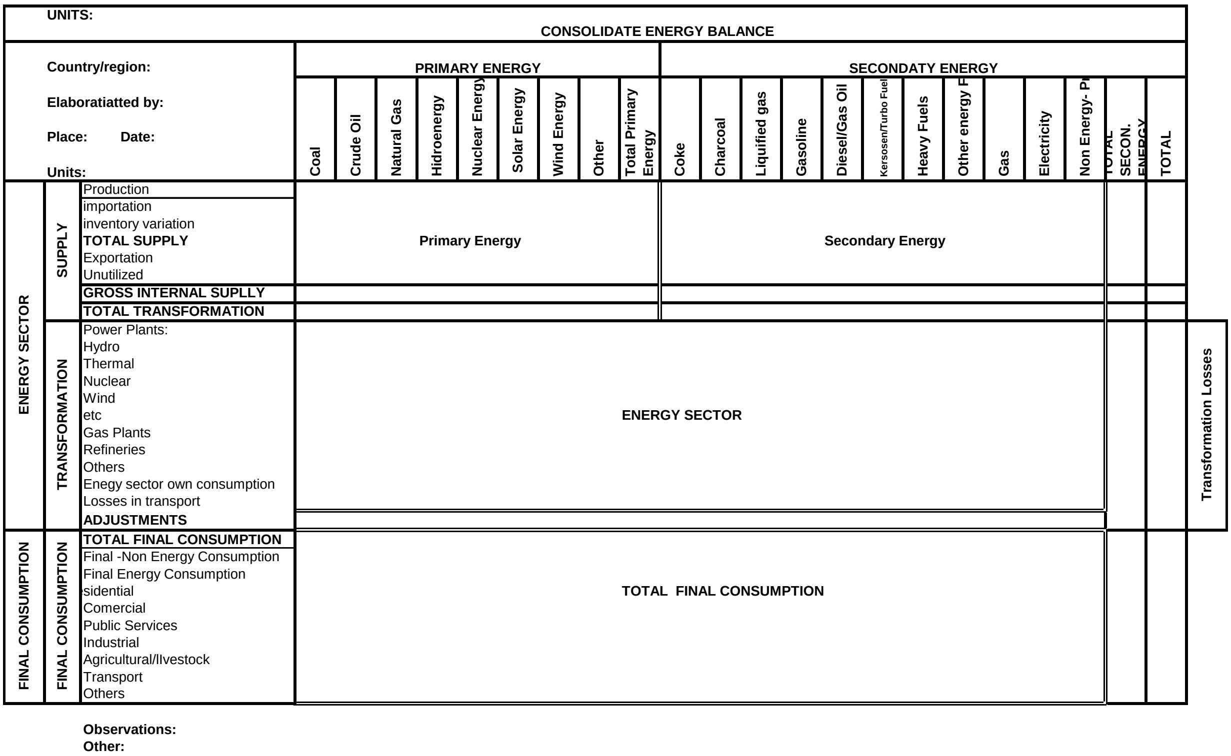

Figure 30 Energy balance sheet

According to Vernet, elaboration of the energy balance is recommended as learning tool at the beginning of the energy modeling process. Two of the objectives of the energy balance are to create a base for systematization of energy information and to establish the structure of the energy system (Vernet, 1983). Thus, the energy balance is used as a first approach to understand and model the energy system in Aragón.

9.1 Method

The Energy balance is built in Excel for year 2008. Data was gathered from the Energy Report of Aragón published in September 2009 (DGA, 2007b) and the excel document provided by Sergio Breto (DGA, 2009a).

9.2 Energy balance flow

The energy balance flow of Aragón is shown in Figure 31, where the unit used is toe. Each fuel is represented with a line in a different colour.

Starting from the left in Figure 31, there is a column with data about the energy inputs and the exports. The central column of the Energy balance represents de transformation of the energy inputs into secondary energy, which in this case is electricity and heat. Finally, the last column includes data about final energy consumption, classified by sectors.

For year 2008, the total energy inputs are 6,7 Mtoe, from which 3,8 Mtoe goes to transformation, 0,3 Mtoe to storage and and 2,6 Mtoe goes directly to consumption. The total final consumption is 3,9 Mtoe.

The total outputs from the transformation are 2,3 Mtoe, giving and overall efficiency of the transformation technologies of 60%. From the 1,9 Mtoe of electricity that are generated, 0,9 Mtoe are exported.

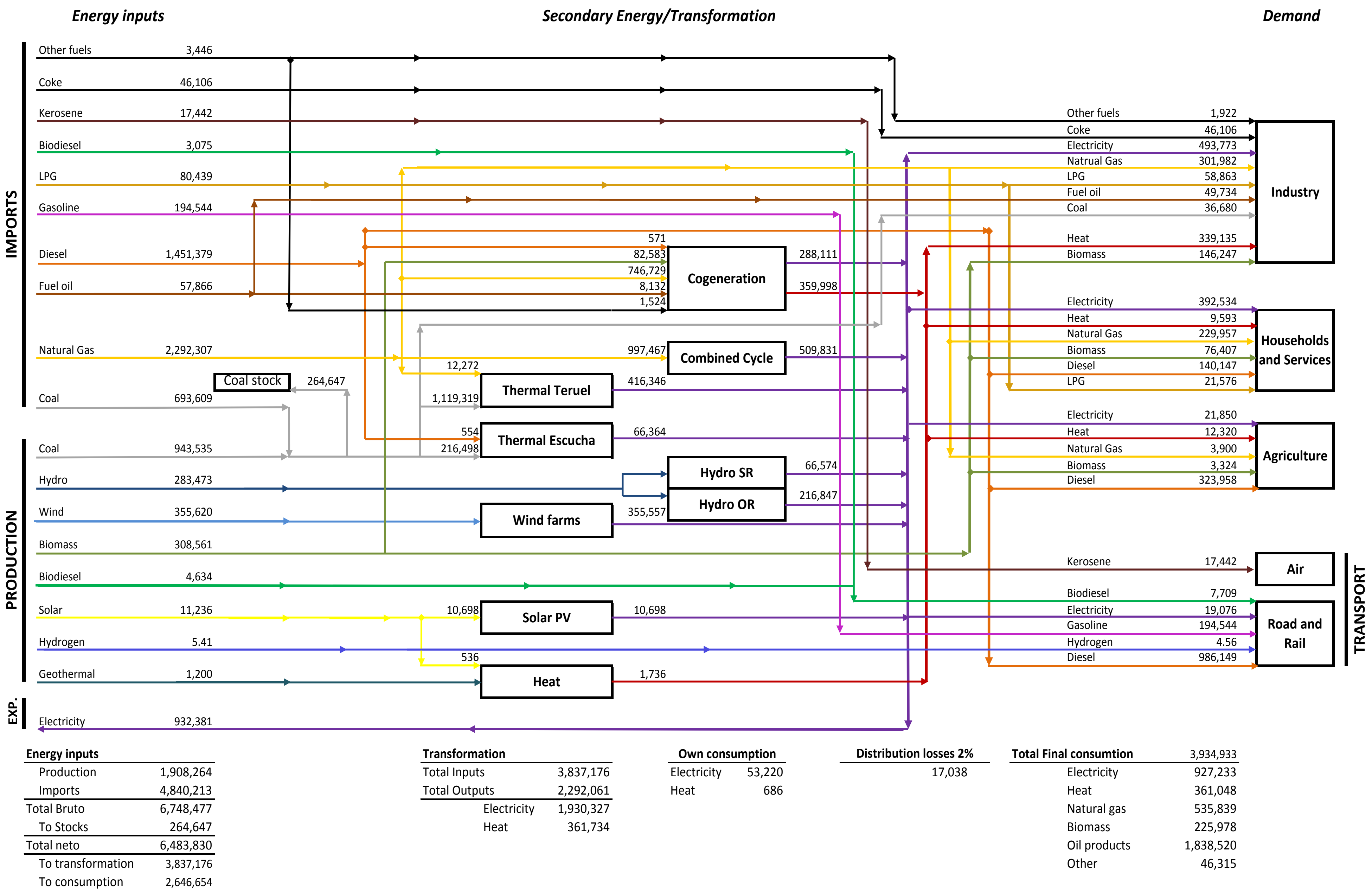

Figure 31 Energy balance for Aragón, year 2008. Units: toe. Source: (DGA, 2009a)

10 LEAP

LEAP is a tool that can be used to create simulation energy models. It was created by the Stockholm Environment Institute and today it is used by several organizations and by more than 85 countries to report to the United Nations Framework Convention on Climatic Change. LEAP is available online (COMMED, 2010).

LEAP was chosen because of its adaptability and simplicity, and because it presents results in a different ways, including graphs, that can be export to Excel. The data structure is adaptable to the availability of data and requirements are relatively low in comparison with other energy modeling tools.

All data and the model in LEAP are available upon request.

10.1 Method

LEAP has built-in calculations that will give results for energy parameters, environmental effects and cost-benefit analysis.

The procedure to use LEAP has been:

- Create the model:
    - Create the data structure. In order to do this, data available was analyzed and organized in a hierarchical tree. This tree is included in Annex 2.
    - Enter the reference energy data, with 2008 as base year for calculations, and key assumptions, such as population, number of households, costs, etc.
- Create different scenarios and implement them in LEAP.
- Analyze and compare scenarios. LEAP provides several views of the results to make the comparisons easier. Charts and tables can be exported to Excel.

To see how LEAP perform the calculations and the model structure, see Annex 2.

10.1.1 Data needed to develop scenarios

The main sources of data used to create scenarios are listed in Table 9. The three first reports have been used in short term forecast. The four following have been used in long term forecast. The last report is used for the electric car scenario.

The detailed procedure and data used to develop each scenario explained in following chapters.

Table 9 Main references for scenario development.

Source name	Description
Plan Energético Aragonés 2005-2012[36] *(DGA, 2005b)*	Reference for the short term development.
Avance del informe del sistema eléctrico español[37]*, 2009* (REE, 2009)	Includes capacity changes in 2009, expected changes for CC until 2011 and coal thermal until 2010.
Informe macro sobre la demanda de energía eléctrica y gas natural, y su cobertura[38] *(CNE, 2009)*	Includes expected changes in hydropower, as well as other information.
European Energy and Transport – Trends to 2030. Update 2007(Prof. P. Capros et al., 2008).	Trends for European countries until 2030. DG TREN in the report.
Europe's Share of the Climate Change (Heaps et al., 2009)	Uses DG TREN forecast and updates them to generate scenarios in LEAP. The authors of the report were contacted and provided information about the data.
Prospectiva de generación eléctrica 2030[39] (UNESA, 2007)	Electricity generation forecast hat introduces the point of view of the Spanish companies.
Acuerdo político para la recuperación del crecimiento económico y la creación de empleo[40] *(Ministerio de Economía y Hacienda, 2010a)*	Includes a proposal of energy mix in 2020 from the Spanish government.
Estrategia integral del vehículo eléctrico[41] (Ministerio de Economía y Hacienda, 2010b)	Plan to support electric vehicles. The aim is to have 250,000 electric vehicles in Spain in 2014

[36] Energy Plan of Aragón, 2005-2012
[37] Preview of the Spanish electrical system yearly report for 2009.
[38] Report on electricity demand and natural gas and their supply.
[39] Electricity generation forecast 2030
[40] Political agreement for the recovery of economic growth and employment creation.
[41] Comprehensive strategy for the electric vehicle.

11 Business as usual scenario (BAU)

Business as usual scenario (BAU) describes how the energy system in Aragón could evolve if current policies remain unchanged. Assumptions are made taking into account existing reports (see Section 10.1.1), and historical trends (see Sections 4, 5 and 6). Annex 3 explains some issues in more detail.

11.1 Scenario description

11.1.1 Key assumptions and emissions

Table 10 includes all the key assumptions of the BAU scenario, units, values for 2008, the conditions of development introduced in LEAP and the source for that condition. Source cells are blank when there is no changes from the base year or the changes are assumptions.

When forecast for Aragón could not be found, forecasts for Spain were introduced in LEAP and the program calculate the forecast for Aragón using the Spanish as a guide. Historical data shows that there has been a similar development of economical parameters in the past.

The variable Air Traffic Units is included to measure air transportation activity later in the demand branch. One traffic units is either one passenger or 100 kg of goods (Ministerio de Fomento, 2008).

To calculate emissions, LEAP provides data in a database called TED. Each fuel is liked with it emissions through this database. IPCC emission values are used it this study.

11.1.2 Demand

Table 11 includes all the demand data of the BAU scenario, units, values for 2008, the conditions of development introduced in LEAP and the source for that condition. Source cells are blank when there is no changes from the base year or the changes are assumptions.

The RCS sector final energy intensity is set to grow as the income from Aragón. The assumptions for energy shares in 2030 are made taking into account forecast from DG TREN for Spain, which indicate that variations will not be important. However electricity and natural gas will increase. At the same time, oil products and biomass will decrease. Heat demand will increase, mostly due to solar thermal (Prof. P. Capros et al., 2008, Heaps et al., 2009).

In the agricultural sector, final energy intensity is set to grow as its value added. No fuel share changes are introduced in the BAU scenario, both due to historical trends and DG TREN forecast.

Industrial sector final energy intensity also grows as its value added. The historical development in the industry sector shows that the share of electricity remains approximately constant, and it will continue constant in the BAU scenario. Since cogeneration is expected to grow according to DG TREN. The rest of the fuel’s shares in the final industry will remain constant.

Table 10 Input data and sources for the key assumptions branch in BAU scenario.

	Units	2008	Expresion	Source
Demography				
population	[thousand people]	1.326,9	untill 2020: INE forecast after 2020: linear forecast	INE
household size	[people]	2,56	Untill 2020: growth 0.9% after 2020: growth 0.5%	DG TREN for Spain
households	[thousand people]	503,05	population/household size	
Economy				
GDP Spain	[million €]	1.088.502		Europe's share of the climate change forecast
GDP Aragon	[million €]	34.088	Grow as GDP Spain	INE for 2009, Europe's share of the climate change forecast
GDP per capita Aragon	[thousand €]	25,69	GDP Aragón/population	
Economy: Value Added				
Agriculture	[million €]	1.331	GDP*structure VA Aragón Agriculture	
Industry	[million €]	10.377	GDP*structure VA Aragón Industry	
Services	[million €]	22.383	GDP*structure VA Aragón Services	
Economy: Value Added structure in Spain				
VA Industry		29,70%	Remainder	
VA services		67,17%	Interpolate 2010: 66.8%; 2020: 66.2%; 2030:67.7%	DG TREN
VA Agriculture		3,32%	Interpolate 2010: 3.5%; 2020: 3.3%; 2030:3.1%	DG TREN
Economy: Value Added structure in Aragón				
VA Agriculture		3,90%	Grow as structure VA Spain	
VA Industry		30,44%	Grow as structure VA Spain	
VA Services		65,66%	Grow as structure VA Spain	
Transport				
Air traffic units	1 traffic unit = 1 person or 100 kg goods	818.245	untill 2020: growth 1.9% after 2020: growth 1.7%	Europe's share of the climate change forecast
Spanish electricity demand				
Spanish electricity demand	[million toe]	21,41	Until 2020: growth 1.6% after 2020: growth 0.6%	INE for 2009, Europe's share of the climate change forecast
Emissions				
Database TED included in LEAP has been used.				

Table 11 Input data and sources for the demand branch in BAU scenario.

	Units	2008	Expresion	Source
Demand				
Branch: Demand\Households and Services\All devices				
Final energy intensity	[toe/person]	0,66	Grow as GDP per capita	
Electricity	%	45,11	Interpolate	
Natural Gas	%	26,43	Interpolate	
Biomass	%	8,78	Interpolate	
LPG	%	2,48	Interpolate	
Diesel	%	16,10	Interpolate	
Heat	%	1,10	Interpolate	
Agriculture				
Final energy intensity	[toe/thousand €]	0,28	untill 2020: growth -1.9% after 2020: growth -1.4%	Europe's share of the climate change forecast
Electricity	%	5,98	No changes	
Natural Gas	%	1,07	No changes	
Biomass	%	0,91	No changes	
Diesel	%	88,67	No changes	
Heat	%	3,37	No changes	
Industry				
Final energy intensity	[toe/thousand €]	0,14	untill 2020: growth -1.5% after 2020: growth -1.2%	Europe's share of the climate change forecast
Electricity	%	33,49	No changes	
Natural Gas	%	20,48	Interpolate	
Coal Unspecified	%	2,49	No changes	
Crude Oil	%	0,00	No changes	
Biomass	%	9,92	No changes	
Petroleum Coke	%	3,13	No changes	
LPG	%	3,99	No changes	
Heat	%	23,00	Interpolate	
Diesel	%	3,37	No changes	
Lubricants	%	0,13	No changes	
Transport				
Air	[toe/air traffic units]	0,02	Kerosene demand/air traffic units	Kerosene demand from DG TREN
Transport: Road and train				
Road and train	[toe]	1.207,48	untill 2015: growth 1.66% untill 2020: growth 0.80% untill 2025: growth 0.29% untill 2030 growth -0.25%	DG TREN
Electricity	%	1,6	untill 2020: growth 0,8% untill 2010: growth -3,3%	DG TREN
Diesel	%	81,7	Decrease when biomass increases	Europe's share of the climate change forecast
Gasoline	%	16,1		
Hydrogen	%	0,0		
Biodiesel	%	0,6	Interpolate	DG TREN

For transport, forecasts from DG TREN are mostly used. Kerosene is assumed to be consumed only in air transportation, and electricity only in trains. To compensate the increase in biofuel share, diesel and gasoline decrease their share equally. Notice that electric cars haven't been introduced in the BAU scenario even if currently there are policies to promote them. The aim is to introduce them in a different scenario to be able to compare.

11.1.3 Energy transformation

Table 12 and Table 13 show transformation data of the BAU scenario. Source cells are blank when there is no changes from the base year or the changes are assumptions.

In the heat generation module there are only three possible parameters to change: process share, efficiencies and fuel share in cogeneration. Efficiencies and fuel share in cogeneration remains as in the base year for the BAU scenario. Process share will change slightly, but not in relevant numbers since heat will still be mainly consumed by industry and generated in cogeneration facilities. The conditions are:

- Geothermal production limit is 1200, from historical data.
- Solar thermal percentage of participation will grow as demand for heat in houses grows.
- Cogeneration will cover the remainder heat demand.

The electricity generation module needs two parameters to describe it, the planning reserve margin and the load curve. The planning reserve margin is the surplus of installed capacity that LEAP considers enough to cover demand in any situation. If this variable is set lower than the system needs, it results in unmeet electricity demand. The load curve introduced in LEAP does not include cogeneration, since the program considers the technology as heat generation. The load curve in Aragón is represented in Figure 32.

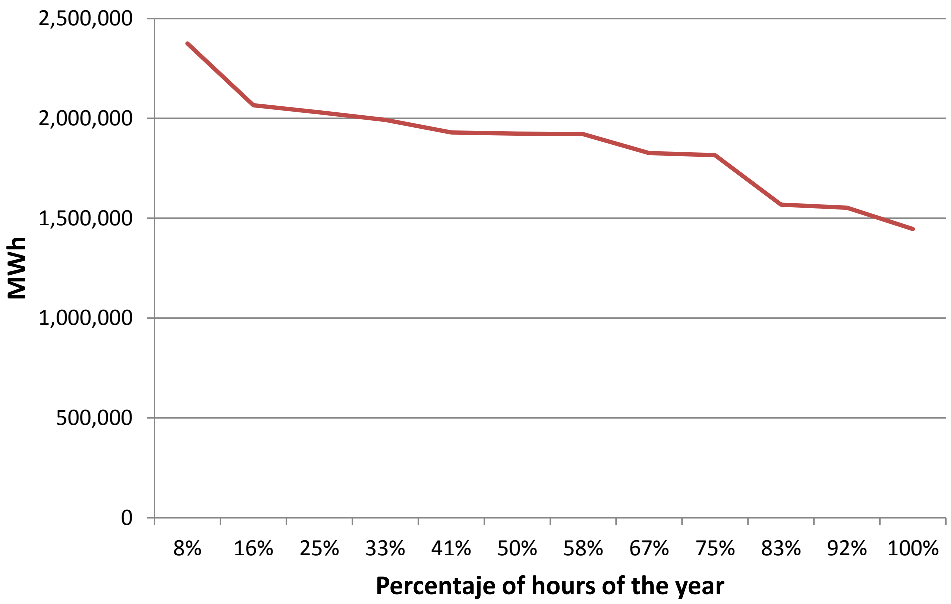

Figure 32 Load curve for year 2008. Source: own elaboration from (DGA, 2009a, DGA, 2009c, DGA, 2009b)

Table 12 Input data and sources for the transformation branch in BAU scenario I.

	Units	2008	Expresion	Source
Transformation				
Distribution losses: Electricity				
Losses	%	2	No changes	
Own use: Electricity				
Own use	%	5	No changes	
Heat generation: Process share				
Solar thermal	%	0,15	Interpolate	
Cogeneration	%	99,52	Remainder	
Geothermal	%	0,33	Interpolate	
Heat generation: Process Efficiency				
Solar thermal	%	100,00	No changes	
Cogeneration	%	43,13	No changes	
Geothermal	%	100,00	No changes	
Heat generation: Coproduct Efficiency				
Cogeneration	%	34,52	No changes	
Heat generation: Variable Cost				
Solar thermal	[€/toe]	1.500		Average EU energy policy data
Cogeneration	[€/toe]	812,13		
Geothermal	[€/toe]	840		
Heat generation: Cogeneration Feedstock Fuels				
86,31	%	89,47	No changes	
11,95	%	9,90	No changes	
1,74	%	0,63	No changes	
Electricity generation				
Planning reserve margin	%	30	after 2019: 45%	Iteration in LEAP
Export target	[thousand toe]	932	Grow as Spanish electricity demand	
Electricity generation: Process Efficiency				
Coal Themal	%	35,79	No changes	
Combined cycle	%	51,11	No changes	
Solar	%	100	No changes	
Wind Power	%	100	No changes	
Hydro OR	%	100	No changes	
Hydro SR	%	100	No changes	
Electricity generation: Exogenous Capacity				
Coal Themal	[MW]	1.341,00	2010: -80 MW; 2012: -80 MW 2019: 366 MW; 2020: 0MW	Energy Plan Aragón, UNESA forecast
Combined cycle	[MW]	1.781,00	2019: +500 MW	REE, CNE
Solar	[MW]	111,80	untill 2020: +500 MW after 2020: grow 7.7%	Assumption using DG TREN
Wind Power	[MW]	1.715,00	Grow 1.3%	Assumption using DG TREN
Hydro OR	[MW]	1.323,00	2013: + 400 MW	CNE and BOE
Hydro SR	[MW]	254,00	No changes	
Electricity generation: Endogenous Capacity				
Add when needed, in this order: 100 MW wind power, 400 MW combinec cycle, 40 MW coal thermal				

Table 13 Input data and sources for the transformation branch in BAU scenario II.

	Units	2008	Expresion	Source
Electricity generation: Dispatch order				
Dispatched as merit order First: solar, wind power, hydro Second: combined cycle Third: coal thermal				
Electricity generation: Maximum Availability				
Coal Themal	%	65,71	Maximum availability since 1992	
Combined cycle	%	38,10		
Solar	%	12,41		
Wind Power	%	18,13		
Hydro OR	%	21,76		
Hydro SR	%	34,80		
Electricity generation: Variable Cost				
Coal Themal	[€/MWh]	40,00	Interpolate	Average EU energy policy data
Combined cycle	[€/MWh]	40,00	Interpolate	
Solar	[€/MWh]	285,00	Interpolate	
Wind Power	[€/MWh]	72,50	Interpolate	
Hydro OR	[€/MWh]	60,00	Interpolate	
Hydro SR	[€/MWh]	67,50	Interpolate	
Electricity generation: Capacity Credit				
Coal Themal	%	100,00		
Combined cycle	%	100,00		
Solar	%	18,89	Technolgy max. Availability/coal thermal máximum availability	
Wind Power	%	27,59		
Hydro OR	%	33,12		
Hydro SR	%	52,96		
Electricity generation: Coal Themal Feedstock Fuels				
Coal Lignite	%	55,30	No changes	
Natural Gas	%	0,90	No changes	
Diesel	%	0,05	No changes	
Coal Anthracite	%	43,75	No changes	

When introducing installed capacity, LEAP has two parameters: exogenous and endogenous capacity. Exogenous capacity is defined by the user, and it includes data of future increases or decreases of capacity that are confirmed. For a detailed explanation on the forecast for each technology, see Annex 3. On the other hand, endogenous capacity is calculated by LEAP, and it is the increase in capacity needed to cover the energy demand. This variable is defined introducing in LEAP which technologies and how much capacity can be added yearly.

Another important parameter that should be introduced in LEAP is the dispatch order, or how the share of the technologies should be calculated. In this case the dispatch order is the merit order, which is the priority of the technologies to generate electricity. Merit order is determined at Spanish level (REE, 2009). Thus, for Aragón, the same merit order is chosen, with the only difference that there is no nuclear energy in the region. Table 12 shows the merit order for the BAU scenario, where 1 represents base load.

The next important variable is maximum availability. Maximum availability is the percentage of hours of the year that a power plant can generate electricity. Maximum historical availability was introduced in LEAP for each technology. Combined Cycle was an exception since the historical availability in Aragón is not representative for the technology. Therefore, in this case, data from Europe's Share of the Climate Change was used.

In order to calculate the reserve margin, LEAP uses a parameter called capacity credit. Capacity credit measures how much of the installed capacity of a technology contributes to the reserve margin. This value is 100% for coal thermal and CC, since they can be used when needed. For renewable energy it is suggested by LEAP to be as the ration between the maximum availability of the technology and the maximum availability of coal thermal. Table 13 shows the capacity credit for each technology.

For both heat and electricity generation, cost data is used from the EU energy policy (Commission staff working document - EU Energy Policy Data, 2007). They cover capital cost, operation and maintenance, and fuel cost. The European commission provides a range of prices, and for this study the average for each technology has been used. For heating, costs are given for each fuel. Therefore the price for cogeneration was calculated as the product of the price of each fuel multiplied by the share of each fuel. Biomass is considered woodchips for this calculation.

11.1.4 Resources

Table 14 shows the maximum annual yield for renewable energy (Greenpeace, 2006) and the coal reserves for the base year (*Gran Enciclopedia Aragonesa online*). No changes are expected.

Table 14 Input data and sources for the resources branch in BAU scenario.

	Units	2008
Resources		
Yield		
Geothermal	[thousand toe/year]	1,2
Solar	[thousand toe/year]	129.183,1
Wind	[thousand toe/year]	16.216,7
Biomass	[thousand toe/year]	773,9
Base year reserves		
Coal Lignite	[million toe]	231,84

11.2 Results

Energy inputs consumption increases to 6,947 ktoe in 2030 after reaching a minimum of 6,037 ktoe in 2009 (see Figure 33). As it can be observed the most important change is the disappearance of coal use. The reason for this is that coal power generation does not recover from the current situation, as it is explained later in this section. On the other hand, natural gas increases its use a 50%, renewable energy (wind, solar, geothermal and hydrogen) 52%, and biomass 51%. Oil products and biomass undergo smaller increases, 6% and 16% respectively. Electricity exports grow 28%, to 1,189 ktoe.

Fuel share in 2030 is represented in Figure 34, which can be compared with fuel share in 2008 (Figure 19 in page 32). Natural gas has a higher importance in the fuel mix in 2030 than in 2008, 35.4% against 49.5%. Also renewable energy (including also biomass and hydro) increases its share to 22.6% from 14.9% in the base year. Coal makes only 0.5% of the energy inputs in 2030 (industrial use). Oil products keep their contribution more or less at the same level.

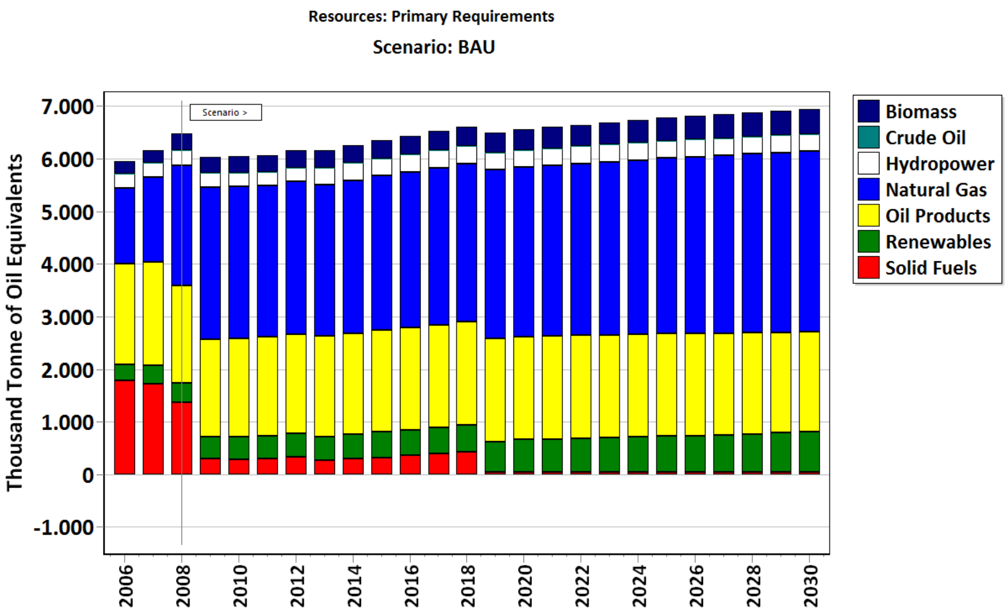

Figure 33. *Energy inputs requirements for the BAU scenario. Biomass includes biomass and biofuels, solid fuels includes all types of coal, renewable includes wind, solar, geothermal and hydrogen.*

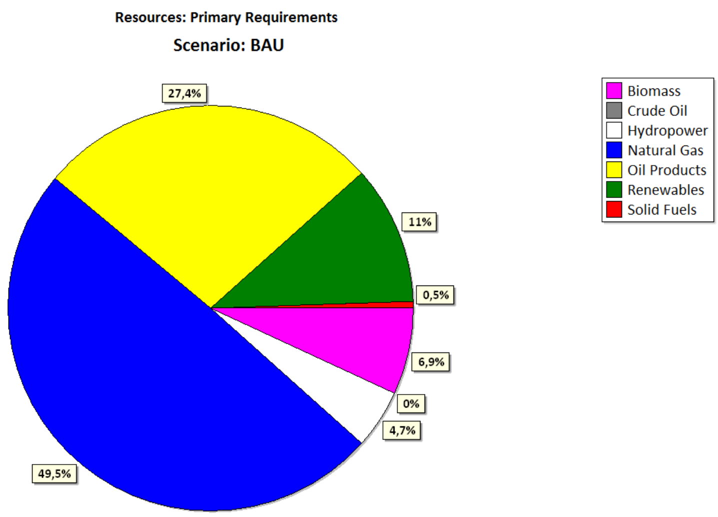

Figure 34. *Energy inputs consumption in 2030. BAU scenario Total energy consumption is 6,806 ktoe.*

Main changes in the transformation branch occur in the electricity sector, since heat generation capacity is not constrained and fuel shares remain almost constant. Installed capacity without including cogeneration grows 44% from 2008. LEAP introduces endogenous capacity in years 2019 and 2020, coinciding with the closure of the last coal thermal power plants, in later in 2024, 2026 and 2028.

The power dispatched also changes during the years. At the end of the simulation period, even if there are coal thermal power plants installed, their role is as reserve capacity. Thus in a simulated year coal thermal does not generate any electricity. Note that coal thermal would generate electricity under certain meteorological conditions, such as a dry year or a year with no wind. LEAP introduces this necessity with the reserve margin.

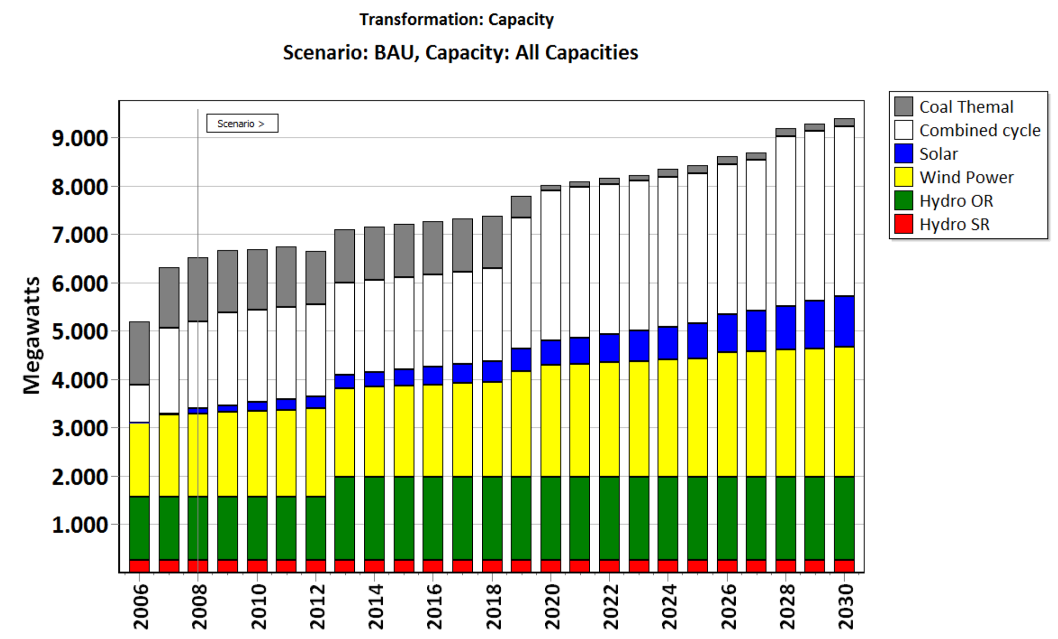

Figure 35. Installed capacity without cogeneration. BAU scenario

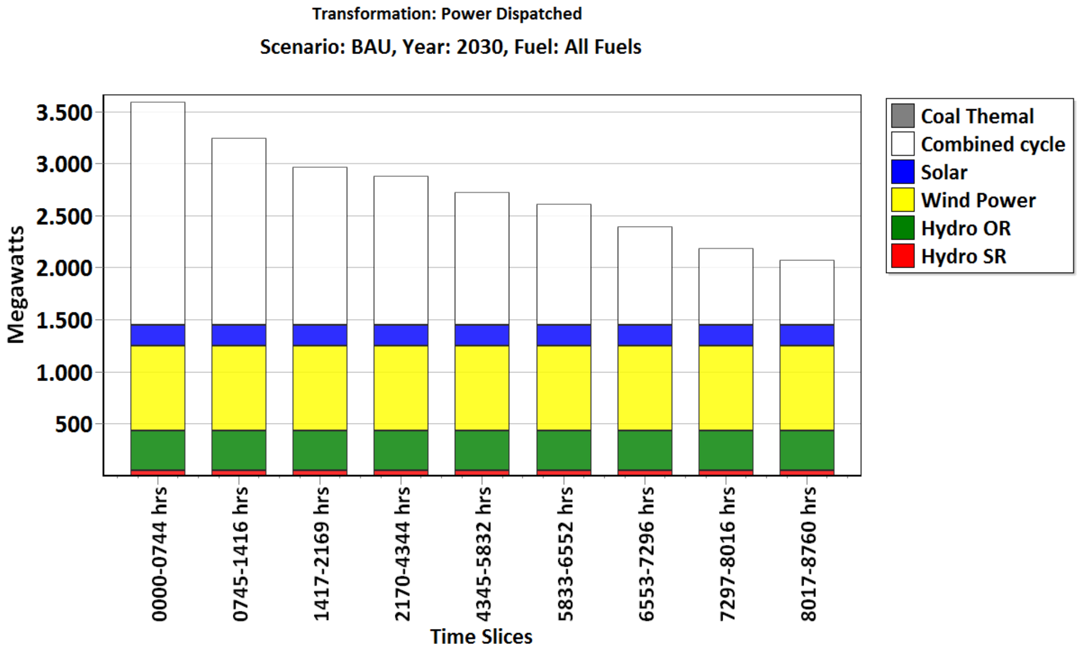

Figure 36. Load curve in 2030. BAU scenario.

Electricity generated without including cogeneration increases to 24,181 GWh in 2030, a 27% more than in 2008. Figure 37 shows the evolution of the electricity generated by the different technologies. The most important change in electricity generation is, again, the decrease of coal thermal to zero generation.

Regarding cogeneration, both heat and electricity generation increase 16% from year 2008.

Technology shares in 2030 when cogeneration is included in electricity generation are included in Table 15. Combined cycle is the most important technology. However, renewable technologies used in cogeneration, without including biomass, account for 45% of the electricity generation. To include biomass for cogeneration should not change this number very much, since biomass is 10% of the total fuel used in cogeneration facilities.

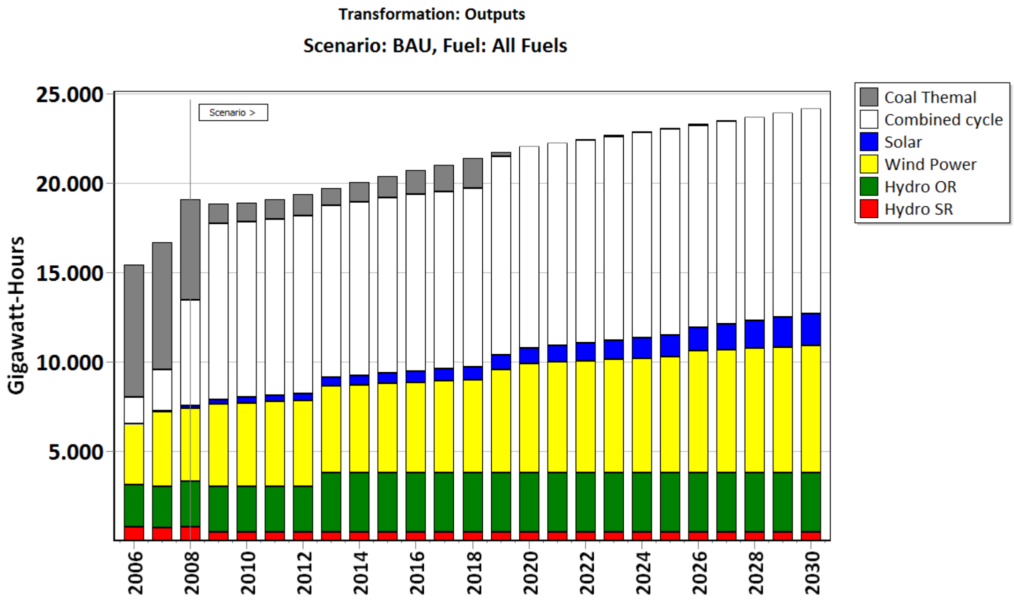

Figure 37 Electricity generation without cogeneration. BAU scenario.

Table 15 Technology share in electricity generation including cogeneration. BAU scenario

Technology	2008	2030
Combined cycle	26%	41%
Coal	25%	0%
Wind	18%	25%
Cogeneration	15%	14%
Hydro	15%	14%
Solar	1%	6%

The last part of the results is the demand branch, or the final energy consumption. As Figure 38 shows, energy consumption increases 579 ktoe from 2008 to 2030. Every fuel increases its consumption. Biomass has the highest percentage increase, 63% from 2008 to 2030. This increase is due to increase in use of biofuels for transportation. Electricity consumption grows 23% during this period. Natural gas increases its final demand in 20%, and heat 16%. Those fuels will substitute oil products to a certain extent; therefore oil product consumption increases only 3%. During the first part of the period, until 2020, oil products consumption increases more, reaching a peak in 2020 with 1957 ktoe. Nevertheless, from 2020 their consumption decreases slowly to 1,895 ktoe in 2030.

The evolution of the final consumption by sectors is less equal. As it can be observed in Figure 39, RCS (households and services in the legend) is the sector that has the highest increase. From 2008 to 2030 the consumption of the RCS sector increases 35%. The second sector with the highest increase is the transportation sector, with 20% increase during the period. This increase is due to oil products until 2020. After 2020, the increase in less important and is caused by an increase of biodiesel consumption.

A slightly different situation is observed in the industry sector. The energy consumption increases only 4% from 2008. This is due to economic crisis until around 2014, and to the implementation of energy efficiency measures included in the predictions of the European Union.

Finally, the agricultural sector decreases its energy consumption 9% during this period. The main driver for this change is again an increase of efficiency in the use of fuels.

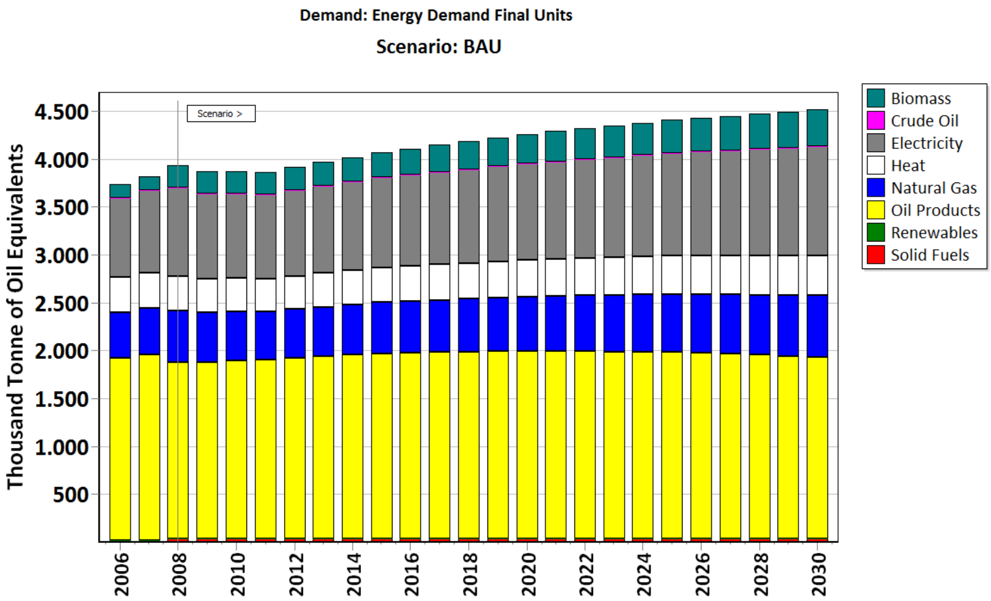

Figure 38 Final energy consumption by sources. BAU scenario

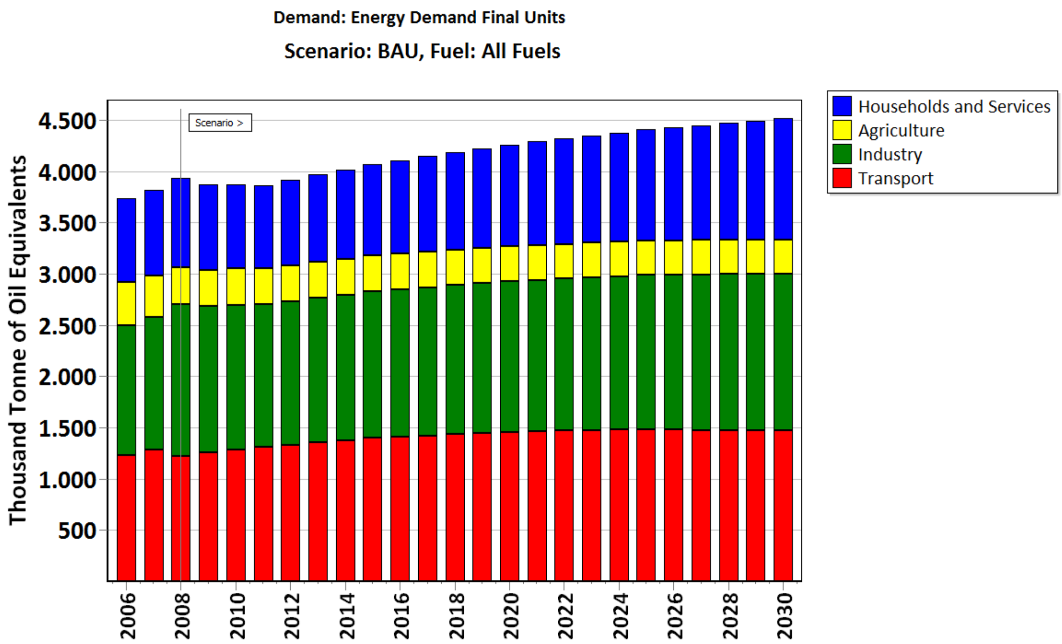

Figure 39 Final energy consumption by sector. BAU scenario.

12 Coal priority scenario (COAL)

The COAL scenario tries to answer the question: “What if coal power plants become base load?” The scenario is built because the Spanish government aims to generate 15% of the electricity with Spanish coal from 2011 (B.O.E, 2010).

12.1 Scenario description

Table 16 shows the changes introduced in the COAL scenario. The rest of the inputs are the same as for the BAU scenario.

Table 16 Changes introduced in the COAL scenario.

Electricity generation: Endogenous Capacity	
BAU Scenario	COAL Scenario
Add when needed, in this order: 100 MW wind power, 400 MW combinec cycle, 40 MW coal thermal	Add when needed, in this order: 100 MW wind power, 40 MW coal thermal, 400 MW combinec cycle.
Electricity generation: Dispatch order	
BAU Scenario	COAL Scenario
Dispatched as merit order First: solar, wind power, hydro Second: combined cycle Third: coal thermal	Dispatched as merit order First: solar, wind power, hydro and coal from 2011 Second: combined cycle Third: coal thermal before 2011

12.2 Results

Figure 40 shows the energy inputs demand in the COAL scenario. The first important result is the increase in use of coal and the decrease in use of natural gas, which is observed when comparing to the BAU scenario. Note that one ktoe of natural gas in substituted by 1.4 ktoe of coal, due to efficiency differences.

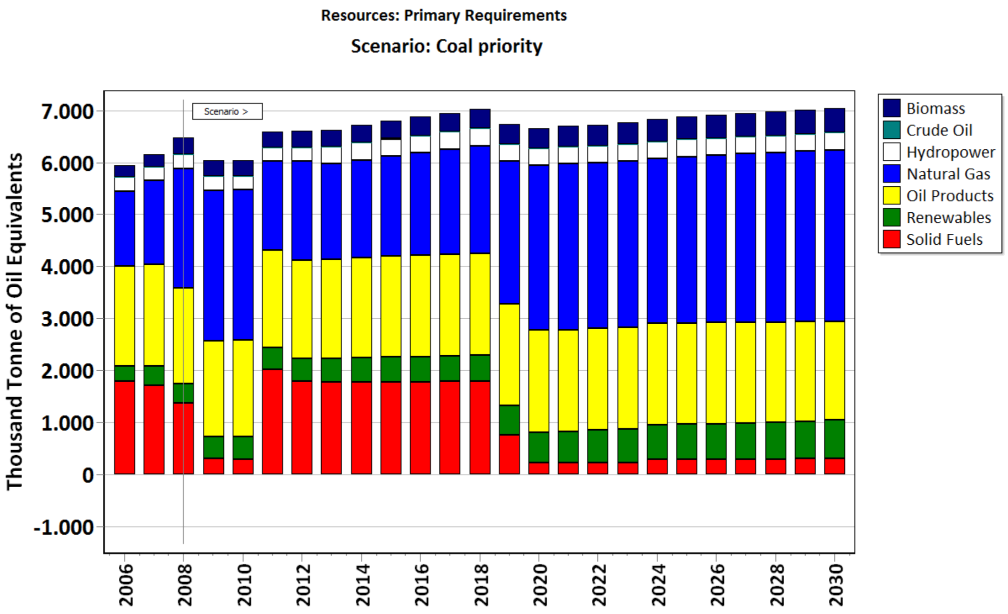

Figure 40 Energy inputs demand in the COAL scenario.

Regarding the transformation branch, the only difference with the BAU scenario is in the electricity generation. As Figure 41 shows, coal thermal substitutes mainly CC generation, from a maximum of 7,200 MWh in 2011 to a minimum of 755 MWh in 2023. After that year the substitution stabilised around 1000 MWh. Renewable energy generates also less energy than in the BAU scenario. These differences are caused by a decrease of the capacity installed of wind power, as observed in Figure 42.

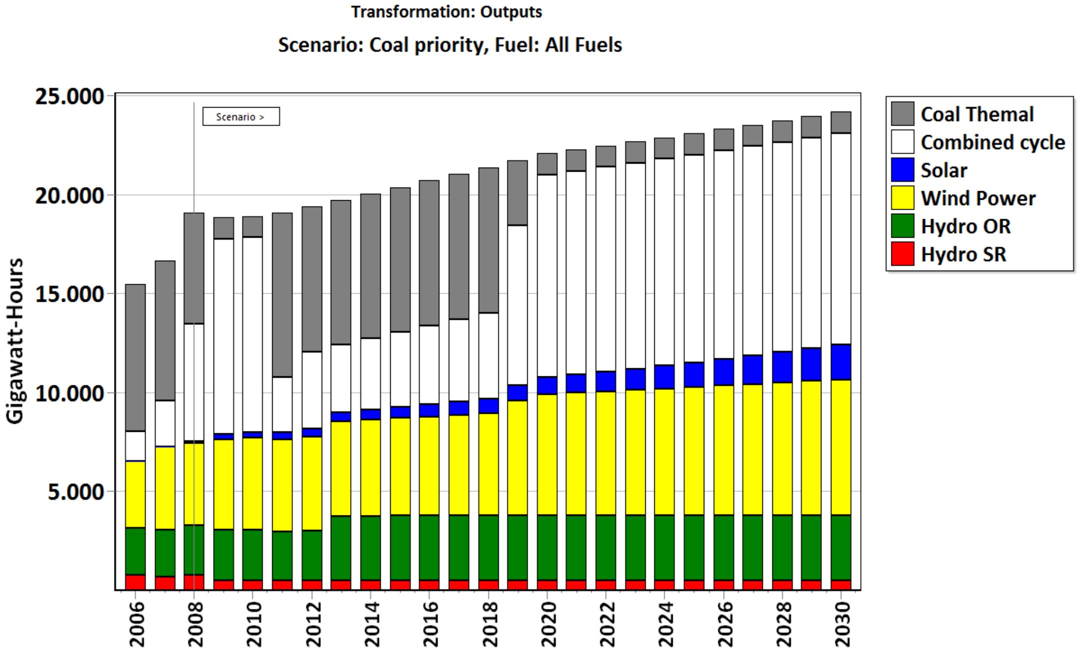

Figure 41 Electricity generation in the COAL scenario.

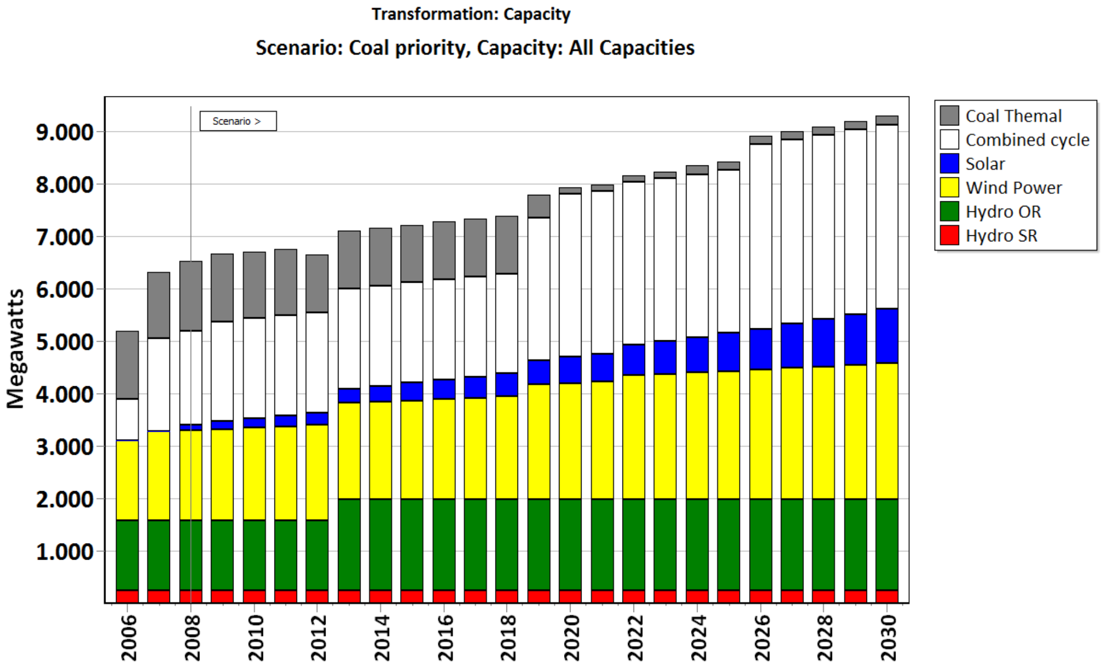

Figure 42 Installed capacity in the COAL scenario.

The last main difference with the BAU scenario is the power dispatched. In year 2030, coal thermal power plants are dispatched as base load with a constant amount of 123 MW, which in the BAU scenario were 30 MW of wind power and 93 MW of CC (see Figure 43).

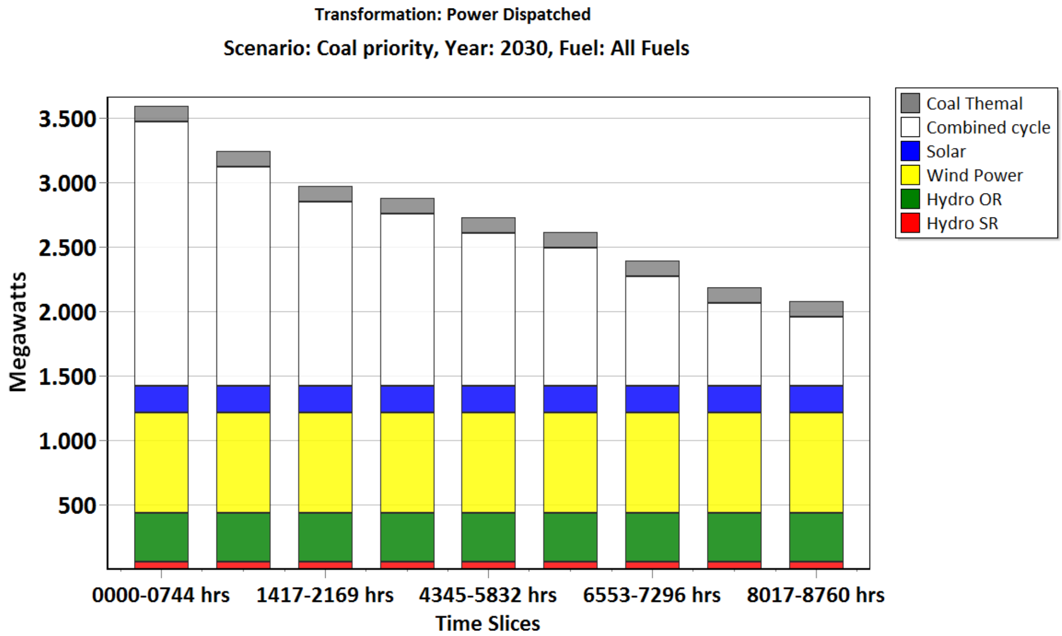

Figure 43 Power dispatched in 2030 in the COAL scenario.

13 Renewable electricity scenario (REN)

In the REN scenario the main assumption is that the only possible power plants to be built use solar or wind energy.

13.1 Scenario description

Table 17 shows the changes introduced in the REN scenario. The rest of the inputs are the same as for the BAU scenario.

Table 17 Changes introduced in the REN scenario.

Electricity generation: Endogenous Capacity	
BAU Scenario	REN Scenario
Add when needed, in this order: 100 MW wind power, 400 MW combinec cycle, 40 MW coal thermal	Add when needed, in this order: 100 MW wind power, 100 MW solar power.

13.2 Results

Figure 44 shows energy inputs demand. The differences with the BAU appear in 2019, when in the REN scenario solar and wind power plants substitute coal thermal generation. For each toe of renewable energy consumed in the REN scenario, 1.9 toe of natural gas that were used in the BAU are not consumed.

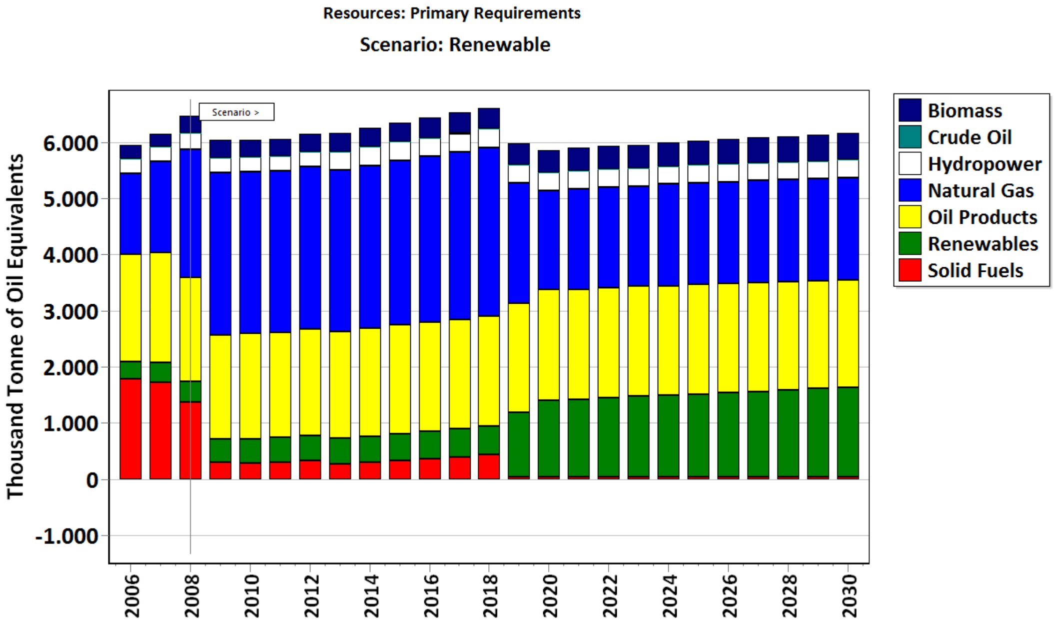

Figure 44 Energy inputs demand in the REN scenario.

Electricity generation from wind power and solar energy increases from year 2019, as can be observed in Figure 45. This causes also an increase ma of installed capacity, since more reserve capacity is needed in order to cover an eventual lack of wind or sun. Figure 46 shows the installed capacity in the REN scenario and the increase from 2019.

Renewable energy also increases its share of the power dispatched. During year 2030, CC only needs to generate electricity two thirds of the year for peak loads, see Figure 47.

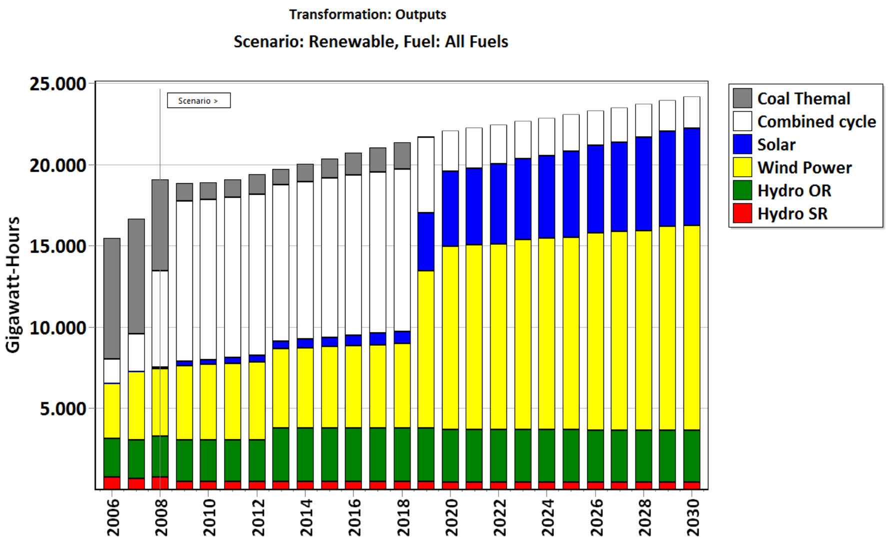

Figure 45 Electricity generation in the REN scenario.

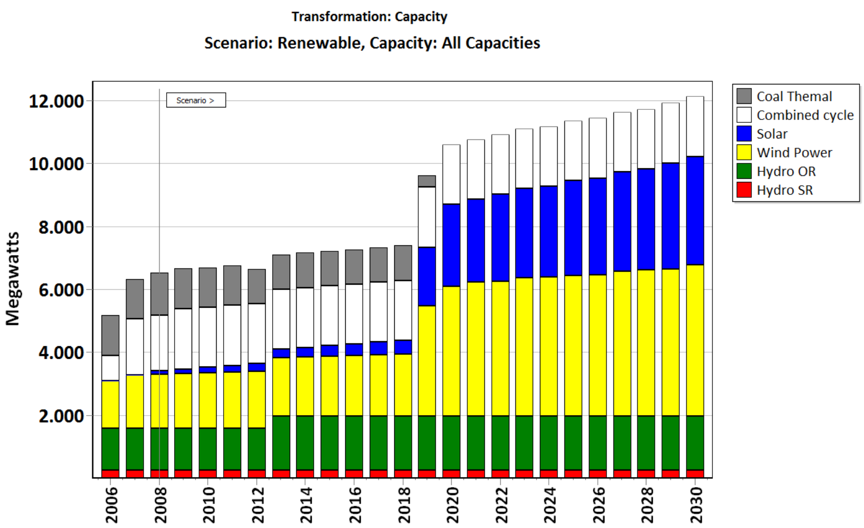

Figure 46 Installed capacity in the REN scenario.

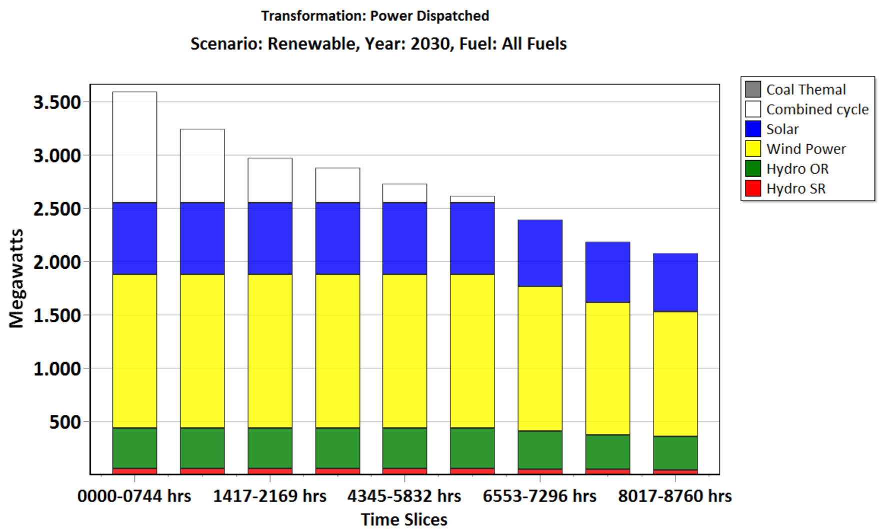

Figure 47 Power dispatched in year 2030 in the REN scenario.

14 Electric cars scenario (ELECAR)

This scenario assumes that the current programs to support electric cars achieve their aims. ELECAR scenario tries to answer the question “What if the current policies are successful and in 2030 all the registered cars are electric and the system moves to the REN scenario?”

14.1 Scenario description

Table 18 shows the changes introduced in the ELECAR scenario. The rest of the inputs are the same as for the BAU scenario. For details on how the input data for the electric cars were calculated, see Annex 3.

Table 18 Changes and new input data introduced in ELECAR scenario.

Electricity generation: Endogenous Capacity		
BAU Scenario	ELECAR Scenario (same as in REN scenario)	
Add when needed, in this order: 100 MW wind power, 400 MW combined cycle, 40 MW coal thermal	Add when needed, in this order: 100 MW wind power, 100 MW solar power.	
Electric cars		
BAU Scenario	ELECAR Scenario	Source
No included	Number of new electric cars per year: logistic forecast calculated by LEAP under the conditions 0 electric cars in year 2008 and 30,000 electric cars in 2030	Comprehensive plan for the electric vehicle, historical data of registered cars
	Electricity consumption: 2.1 MWh/yeat	
	Diesel car consumption: 7 l/100 km	
	Electrc car life: 49 years	IDEA: 18,000 days of life

14.2 Results

The results in this scenario do not only reflect the results from including the electric car in the energy system, but also the result from the REN scenario that had been explained in the previous section. The decrease in the demand of total energy inputs is similar to the decrease in the REN scenario. Only at the end of the simulation period the decrease is higher in the ELECAR scenario, when the decrease in oil products is slightly significant, as it can be observed in Figure 48.

Regarding electricity generated by technology, the situation is similar to the REN scenario. Figure 49 shows electricity generation and Figure 50 capacity installed.

Thus, the important change introduced by the electric cars is the substitution of a part of the oil products used in the transportation sector by electricity, as represented in Figure 51. Electricity demand in year 2030 is 11% of the total Transport sector demand, while oil products demand is 82%. This can be compared with year 2008, when electricity represented 1.4% of the final energy consumption of the Transportation sector and oil products 97%. Figure 52 shows how the demand in the transportation sector decreases due to the effect shown in Figure 51, and thus does the total final demand, especially from year 2020. The rest of the sectors are not affected by this change in the final demand.

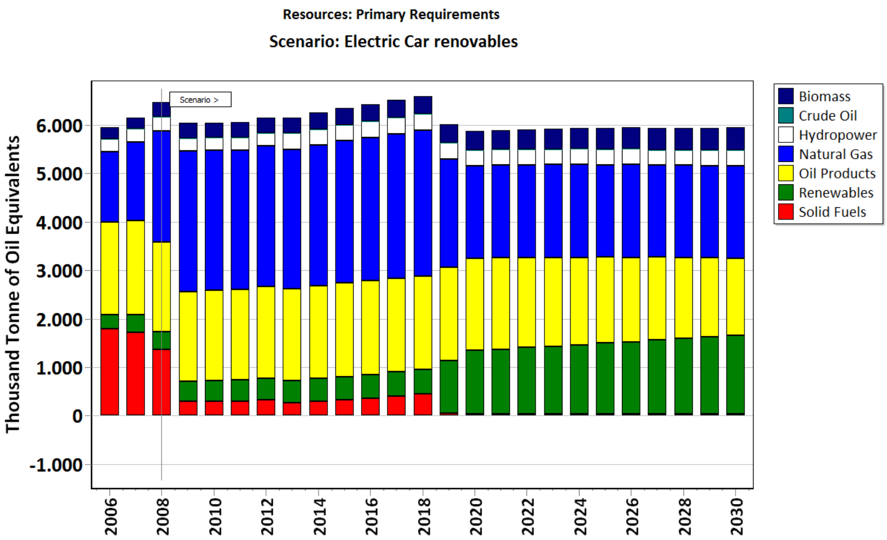

Figure 48 Energy inputs demand in the ELECAR scenario.

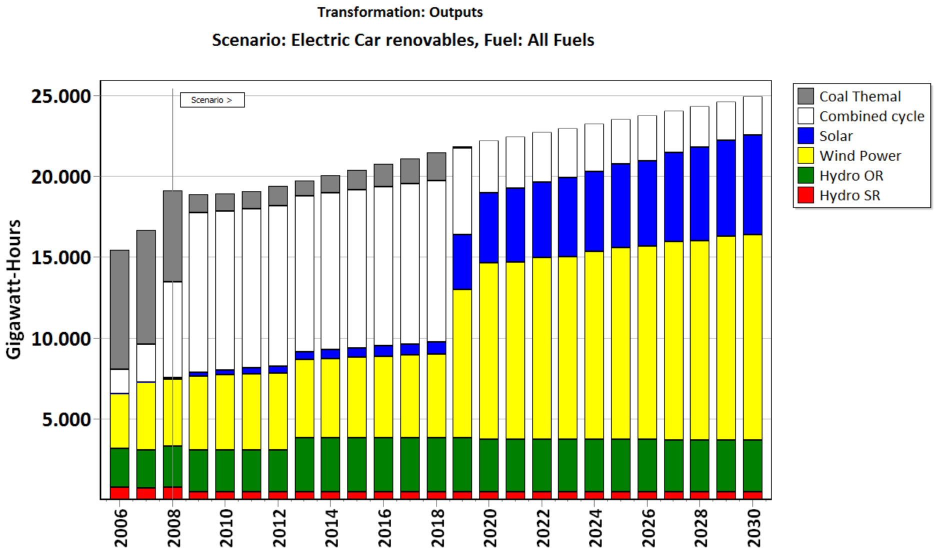

Figure 49 Electricity generation in the ELECAR scenario.

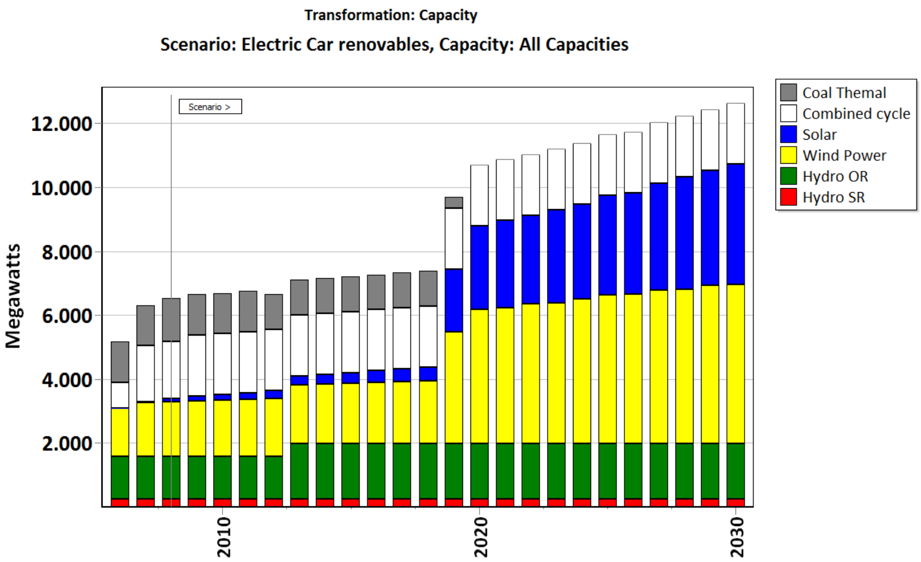

Figure 50 Installed capacity in the ELECAR scenario.

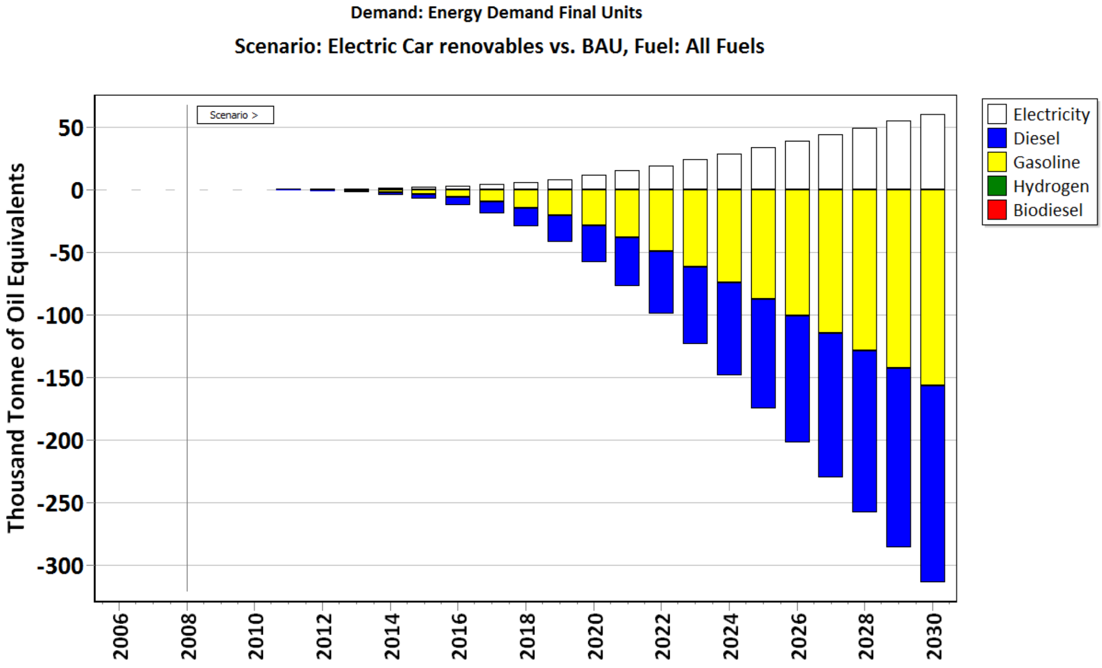

Figure 51 Differences in final energy demand between ELECAR and BAU.

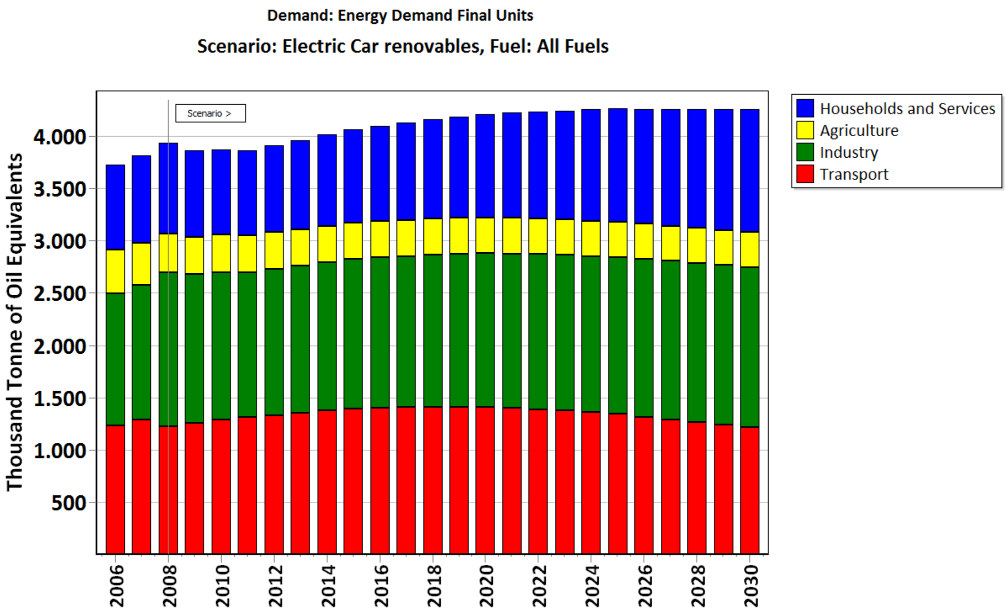

Figure 52 Final demand by sectors in the ELECAR scenario.

15 Emissions and cost.

15.1 Emissions

The Global Warming Potential (GWP) allocated to demands and divided by sectors for the BAU scenario is represented in Figure 53. The sectors with more emissions are the transportation sector and the industry sector. Those sectors are the main consumers of energy; hence they have the highest emissions. The evolution shows a 9% decrease of GWP from 2008 to 2030, a total of 304,375 kt of CO_2 equivalents. During the first years of the period, it is due to the decrease of energy consumption caused by the economic crisis. From 2014, there are two causes for this decrease: First, the decrease of energy consumption in the industry sector due to higher efficiencies and second, the substitution of fuels.

Figure 54 shows the emissions for all the scenarios allocated to demands. As expected, the COAL scenario has the highest GWP, since coal is the fuel with higher emissions. In the COAL scenario the total emission are 20,024 kt of CO_2 equivalents higher than in the BAU scenario. The ELECAR scenario represents the opposite situation. The total savings in this scenario are 28,936 kt of CO_2 equivalents. The REN scenario has also important reduction of emissions in comparison with the BAU scenario, 22,754 kt of CO_2 equivalents.

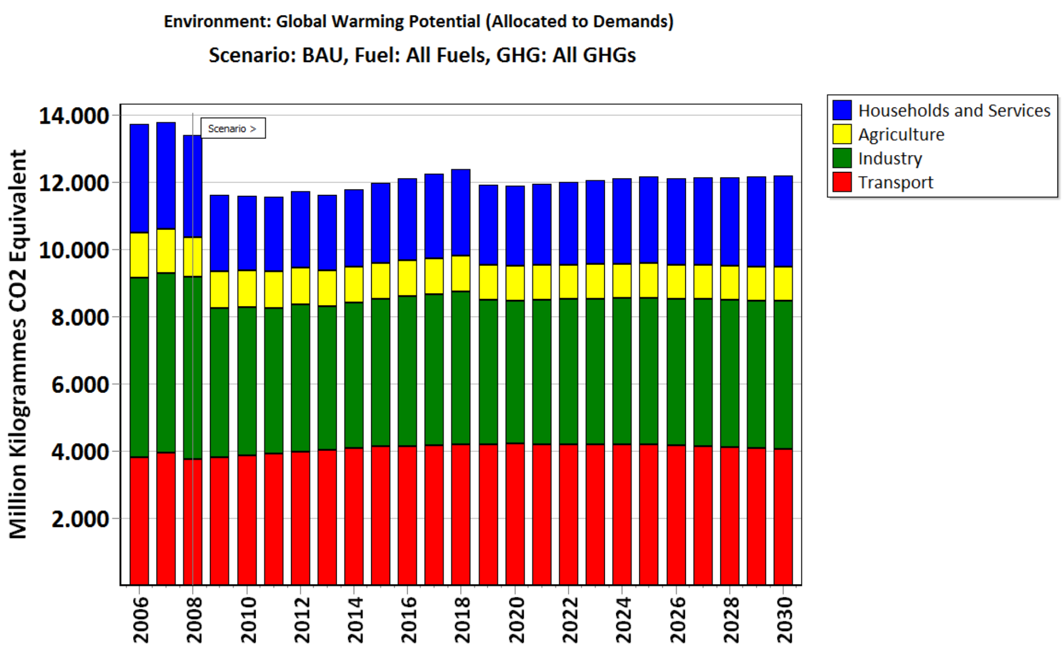

Figure 53 Global warming potential allocated to demands. BAU scenario

15.2 Cost

This analysis does not pretend to be an analysis of the economic feasibility of each scenario. Rather, LEAP provides a tool to compare scenarios and decide which are sociable acceptable.

Costs with no discounting method applied are shown in Figure 55. The only scenario that has less cost than the BAU scenario is the COAL scenario. The savings in this scenario are 3,047 million €. The reason for this is that coal thermal technologies are the cheapest, and the CO_2 prices are not high enough to increase the cost of the scenario. On the other hand, the most expensive scenario is the ELECAR scenario, with a cost of 32,052 million € more than the BAU.

The only policy cost included is the policy in the ELECAR scenario. Without discounting, it represents less than 1% of the total cost of the scenario.

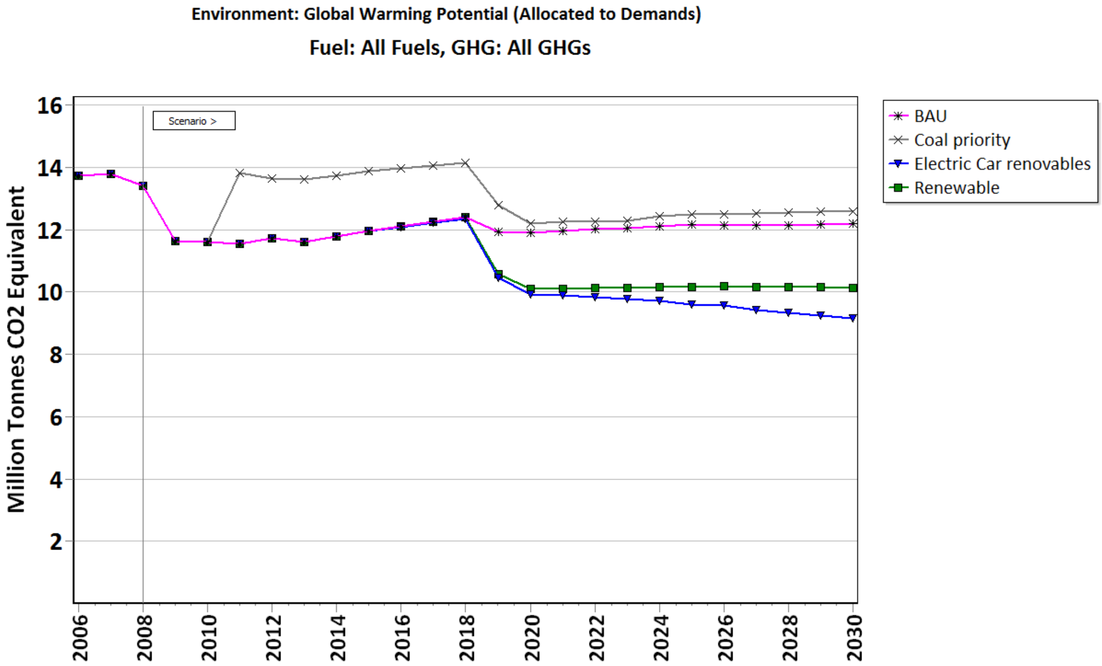

Figure 54 *Global warming potential allocated to demands for BAU, COAL, REN and ELECAR scenario.*

The discount rate affects the cost result because the highest the discount rate, the less importance given to the payments in the future. Therefore, ELECAR and REN are cheaper when the discount rate increase. When it is 10%, as in the DG TREN document, ELECAR scenario is “only” 5,332 million euros more expensive than the base case.

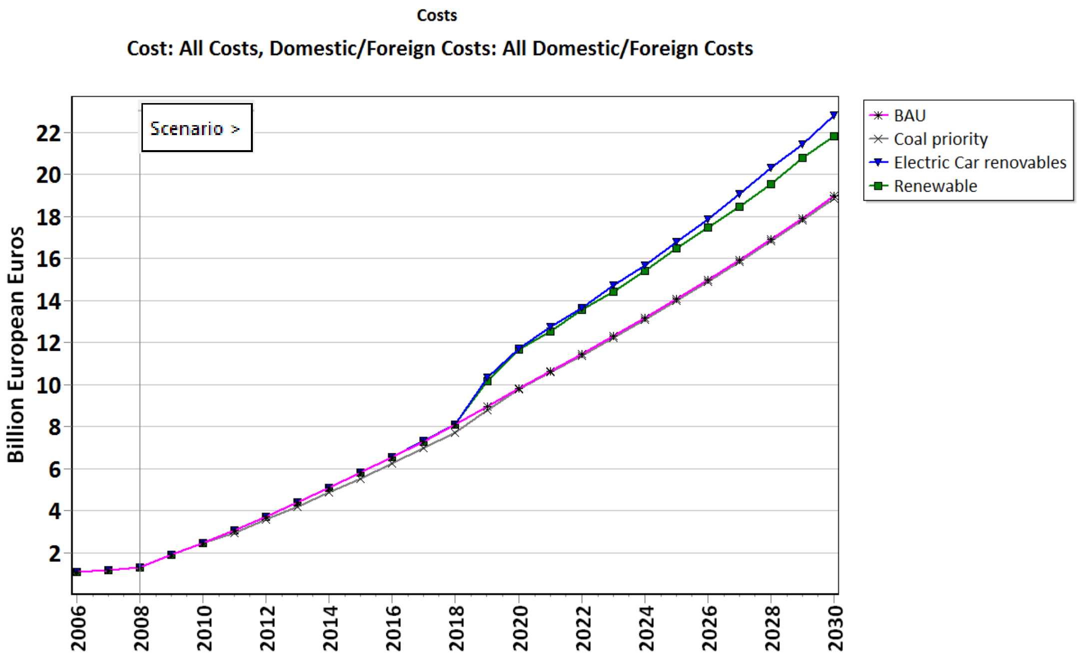

Figure 55 *Cost for BAU, COAL, REN and ELECAR scenario.*

16 Logistic curve versus LEAP

Figure 56 illustrates the difference between the electricity consumption predicted by the logistic curve and LEAP. The logistic curve calculates a demand of 18,493 GWh for year 2030, while LEAP forecasts a demand of 13,249 GWh for the BAU, COAL and REN scenarios and a demand of 13,948 GWh for the ELECAR scenario.

The reason for this difference is that the logistic curve forecasts the demand within the hypothesis that the previous conditions stay constant. On the contrary, the forecasts used to build the model in LEAP include future changes, as increases in energy efficiency or fuel substitution.

Figure 56 also includes the electricity consumption evolution if the growth is equal to the asymptote calculated with the logistic curve program, which is 1.4% yearly. This results in a demand of 15,481 GWh in 2030.

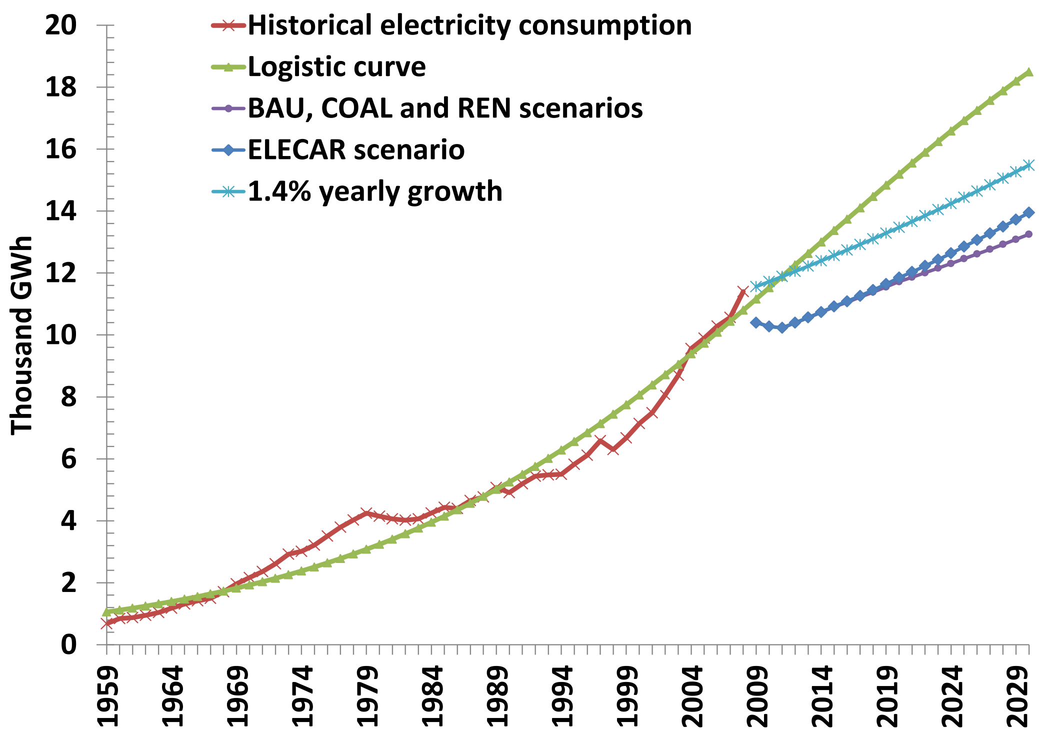

Figure 56 Electricity consumption forecasts.

Regarding installed capacity, the results from the logistic curve, BAU and COAL are quite similar (see Figure 57). When applying the asymptotic yearly growth calculated by the logistic model, the results are also similar. REN and ELECAR scenarios have a much higher need of installed capacity since there are more renewable technologies in the system.

Finally, Figure 58 shows the different results for the electricity generation. In this case the different results are also quite similar, at least in comparison with the differences in the electricity consumption. BAU, COAL and REN scenario would produce 6% more electricity than the calculated by the logistic curve, while the ELECAR would produce 9% more.

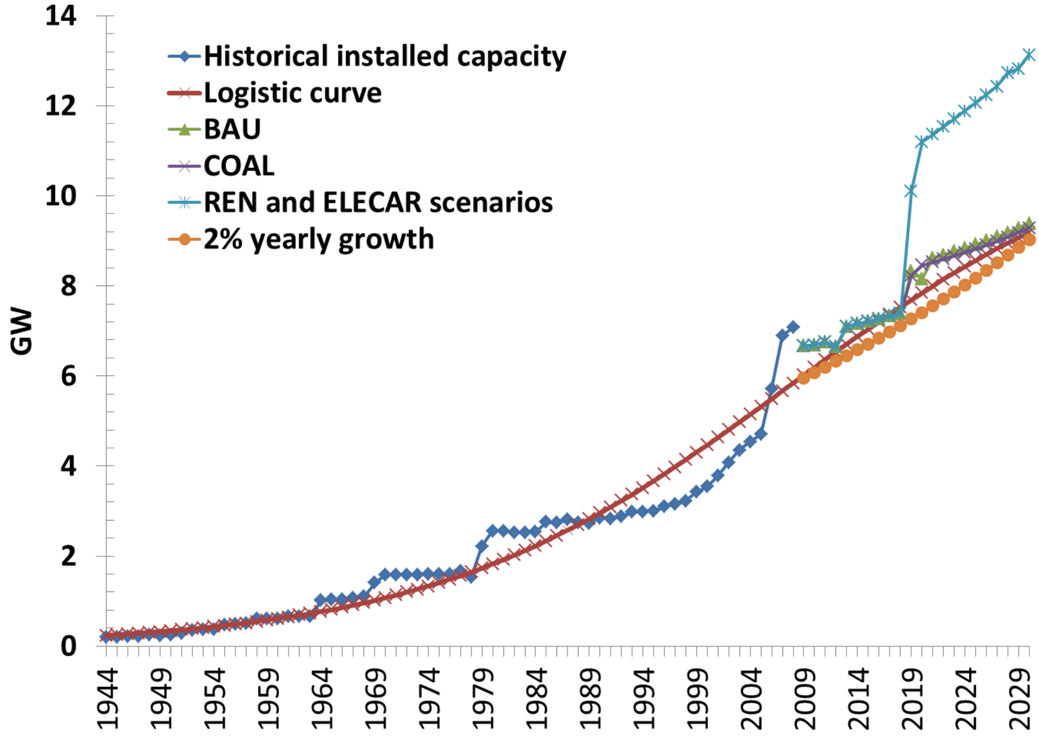

Figure 57 Installed capacity forecasts.

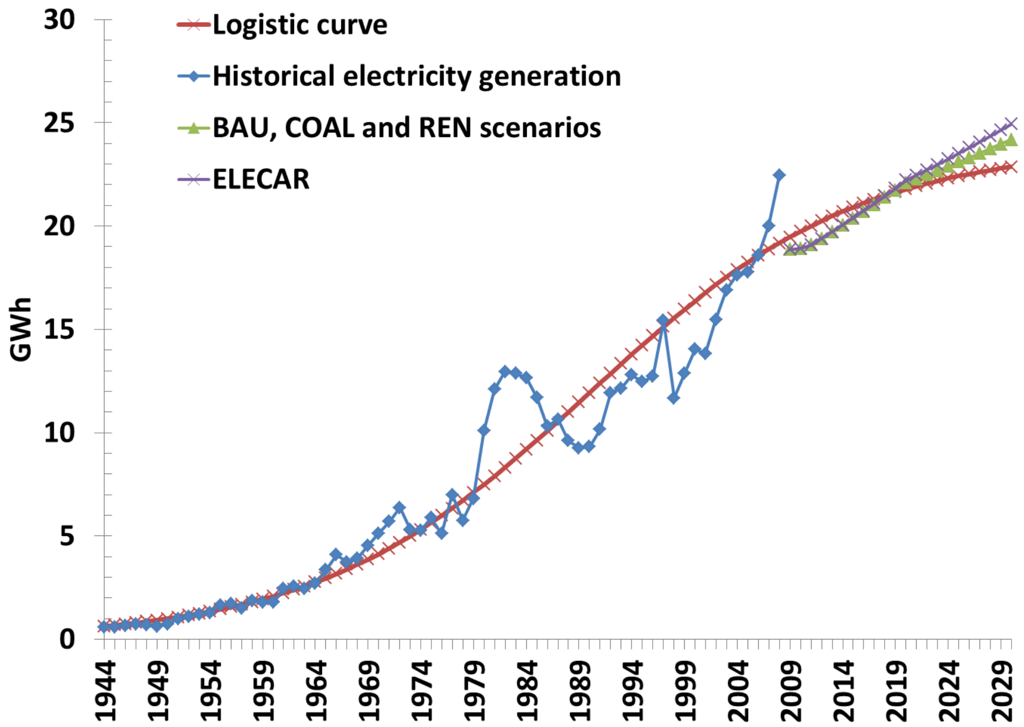

Figure 58 Electricity generation forecasts.

17 Discussion

17.1 Data and information

Most of the data and information needed to develop the study is available in the Internet. For basic information about the energy system, the six-monthly reports published by the DGA are perfect. However, when more detailed data is needed it is not easy to find since energy and environmental data are mixed in the databases. Besides, there is no consistency in the data available in terms of dates, detail, etc.

Books used where easy to find in the regional libraries and some of them where provided by the DGA. However, it is surprising that books published by the DGA are not found in the Internet, including the Energy Plan 2005-2012. The level of detail in those books is very good and important to maintain to carry out energy planning, especially in the demand side.

An important problem is the lack of data at regional level that is necessary for planning and it is only available at national level.

Disagreements between data were also found. For example, some final energy consumption values are different in the Energy balances published in the Internet and in the Energy balances published in books. Sometimes data provided by the Energy department in the DGA and by the IAEST are different, even if the IAEST source is the Energy department.

These problems could be solved by creating an Energy Agency of Aragón. This agency could focus in the energy sector and create a database, and it could approach the energy system as a whole, including also environmental and social issues. The idea of an Energy Agency of Aragón has been already proposed in the Energy Plan 2005-2012 buthas not yet created.

17.2 Plans and forecasts

An important problem found in several of the plans and forecast used was the lack of explanations about the assumptions made. This problem is especially important in the UNESA report, in the proposal of the government and in the plan for the electric vehicle. As a result, it is difficult or impossible to compare or analyse those reports.

In addition to this problem, contacting companies was really difficult. When trying to contact there was no answer or directly a refuse to collaborate. Therefore, the issue of coordination between government and companies plan cannot be addressed in this study. However, important differences are found in the UNESA report and in the government proposal at Spanish level, which suggest an uncoordinated planning.

Since only transmission and distribution plans are compulsory to follow by the companies, several questions arise: what should be the focus of the governmental energy plans? What is the role of energy plans when the sector is liberalized? Is it possible to coordinate government and companies plans in a liberalized market? These questions are not included in the aim of this study, but they could be part of future studies at regional and national level. For energy plans to be successful it is crucial to define clearly government and companies' roles, rights and obligations, as well as objectives, method and reasons to carry on energy planning for each of the actors.

Another general issue found in most of the energy plans and reports is the study of cogeneration as independent from heat demand. Heat demand is the driver for the installation of cogeneration plants, but there is not a study of the future heat demand in any of the documents found. On the contrary, the growth of cogeneration is considered only taking into account the electricity generated. As a result, most of the forecast for cogeneration had failed. A system perspective is therefore useful in Aragón, where cogeneration generates an important part of electricity but it is driven by heat demand.

Another limitation is the classification of biofuels and hydrogen as primary energy. Currently the presence of both fuels in the energy system in Aragón is not important. However, detailed data is needed to know if it is desirable to increase their presence in the system. In order to gather those data different companies were contacted, with no answer.

17.3 LEAP and results

LEAP has been a useful tool, but not without problems. LEAP contains bugs that are frequently fixed by the developers. The main problem is that when a bug is found by a user (as it happened during this study several times) and it produces wrong results, the only solution is to wait for a new version On the other hand, the developers are available by the internet and provide high quality support. Thus, LEAP is perfect to use as a tool for accounting data and to understand effects of different changes in the energy system, but it can be problematic when there is an important deadline that has to be met.

Logistic curves provide two important results. First, the electricity consumption in 2030 is 40% higher than the result provided by LEAP. The reason for this is that the logistic curve does not introduce efficiency measures in the demand side, changes in life style or other factors, while data introduced in LEAP does. On the other hand, the rest of the results are quite similar. This illustrates how different can the results be depending on the method used. To determine which method is better is not a part of this study, but it could be a useful issue to study in the future, as well as how to combine different methods to achieve a better result in the energy plans for Aragón.

The second important result is the different development between installed capacity and electricity generation, where a surplus of installed capacity is observed. This is due to 3 factors:

- Installed capacity without use. Combined cycle plants are only used as peak load, but it is the technology with more installed capacity in Aragón.
- The introduction of renewable technologies, that produce less electricity per MW installed.
- Coal thermal has decreased its generation, but it has the same installed capacity.

In the following paragraphs the most important features of each scenario will be discussed. The most important change in the BAU scenario is the increase in use of natural gas in electricity and heat generation, and also in final demand. Coal use almost disappear and new capacity is introduced only when existing coal power plants are closed, in 2019. This shows again the surplus of installed capacity in Aragón. The increase of demand could be covered by the existing capacity installed in CC and coal thermal and an increase of renewable energy. Regarding final energy demand, RCS sector has the highest increase, since industry and agriculture are expected to apply efficiency measures.

Substitution of coal by natural gas is the main feature in the COAL scenario. Thus, energy security is increased since coal partially a local resource. There is a small decrease in the use of renewable energy to produce electricity.

In the ELECAR scenario renewable energy substitutes natural gas, but only from 2019, when the existing coal thermal power plants close and electric cars are introduced in the transportation sector. The energy security in this scenario is even higher than in COAL and it has the lowest emissions.

The REN scenario is similar to ELECAR, but only introducing renewable energy. Therefore emissions are slightly higher than for ELECAR. However, they represent an important decrease from the BAU and COAL scenarios.

Problems that could arise in the REN and ELECAR scenarios, such as intermittency or grid issues, are not considered in this study, but should be considered in future studies. To deal with the intermittency problem of wind and solar power, LEAP requires a reserve margin capacity of 30% until 2019 and 50% after that. However, a deeper study should be carried out to know what could happen in a day with no wind or in a year without water.

The aim of LEAP's cost analysis is to provide guidance to choose a socially acceptable path, but it is difficult to achieve in this study due to time limitations. Currently only the cost of the policy to promote electric car until 2014 is known. However, this part of the program could be very useful for planning since different social costs can be introduced and changed.

The cost analysis shows that the ELECAR scenario is the most expensive scenario, REN scenario is close to ELECAR and COAL is the cheapest. Therefore a highest price of CO_2 is needed for the renewable technologies to be competitive in the market. On the other hand, if renewable technologies penetrate more in the market, as in ELECAR and REN, they would be cheaper than expected in this project.

18 Conclusions

In the list below the conclusions from the master thesis are summarized:

- The logistic curve results in a 40% higher electricity consumption than the one calculated by LEAP. The results for the installed capacity and electricity generation are quite similar, except for installed capacity when renewable energy is introduced.
- There is a surplus of installed capacity in Aragón.
- In the BAU scenario, natural gas substitutes for coal and coal disappears from electricity generation. RCS sector has the major increase in energy demand, while industry and agriculture are supposed to apply efficiency measures. Transport sector increases energy demand but introduces biofuels at the end of the period.
- In the COAL scenario, energy security increase, and the cost is the lowest. However it is the scenario with highest emissions.
- The REN scenario produces a relevant decrease of the emissions, but the ELECAR scenario has the lowest emissions. The energy security is higher, but both of them are expensive
- No new endogenous capacity is added by LEAP until the existing coal power plants close in 2019 in any of the scenarios.
- The cost analysis tool provided by LEAP has much more possibilities than those that have been use in this study. It could be very useful to compare cost of different policies and include externalities and social costs.

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