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El sistema energético de Aragón. Estrategias para afrontar el futuro

The Energy System in Aragón facing the Future

Informe original

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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 Master Thesis is divided in two parts. The first one focuses in the electrical system and its evolution. The second one included the energy sector and simulates different scenarios for its development.

The first step is a literature review to find historical data about the energy system, and more in detail about the electrical system. Then the logistic curves for electricity consumption, installed capacity and electricity generation are calculated. For the second part, the program used is LEAP. Four scenarios are built: the business as usual (BAU), coal priority (COAL), renewable electricity (REN) and electric cars (ELECAR).

During the development of the Master Thesis 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. However, it is not robust. The main conclusion from the report is that both REN and ELECAR decrease carbon emissions. On the other hand, the costs of those scenarios are highest. COAL is the cheapest scenario, but with more emissions. The electricity generation increase needed in the ELECAR scenario is not as important as first expected.

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

Key words: Energy, Aragón, System aproach

Contents

PREFACE

This Master Thesis subject was suggested by Germán Maldonado. It was carried out in cooperation with Inmaculada Arauzo from the University of Zaragoza and with the Unit for Energy Planning in the Department of Energy and Mines of the Diputación General de Aragón (DGA, regional government of Aragón). This study was made from January 2010 to September 2010 in the division of Energy Technology in the department Environment and Energy.

Although the thesis has an academic purpose, the results can be relevant for the DGA, the university and even companies, since they can use them to decide about their future actions regarding the energy system.

Göteborg September 2010

Marta Rodríguez

1 Introduction

1.1 Goal and Scope

The main goal of this thesis is to study the development of the energy system in Aragón and simulate and analyze some future options for its development. A systems perspective is used, focusing on the whole system and the relations between different parts.

The master thesis is divided in two parts. The aim of the first part is to perform a historical study to understand the socio-technical system. The most important actors and factors are identified. In the second part the purpose is to simulate and analyze different "what-if" scenarios, including changes in the energy demand, technologies, emission constraints, etc.

System boundaries for simulation in LEAP are shown in Figure 1. In the transformation part, only electricity and heat are included. Although LEAP allows simulating coal mining, oil refining, biofuels production, etc., due to time and data availability, they will not be included. Other reasons to not include this are that DGA includes oil products, biofuels and hydrogen as primary energy. Transformation of oil in other products is not considered since it does not occur in Aragón. Biofuels and hydrogen play a small role in the energy system. Therefore the only important activity not included is coal mining. From 2002, own consumption of energy in coal production is always bellow 3% of the total coal produced, with the exception of 2008 when it is 5% (Foro de la Industria Nuclear Española, 2010). Thus, not including coal mining should not have a relevant effect in the results of the study.

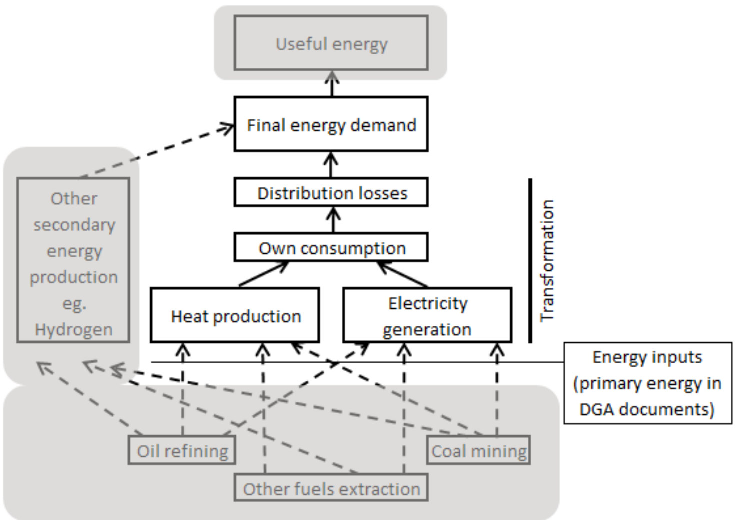


Figure 1. System boundaries for simulation in LEAP. Blocks on the grey background are not included in this study.

In other to avoid possible misunderstandings, what the DGA considers as primary energy will be called in this document energy inputs. Thus, energy inputs includes coal, natural gas, oil products, biofuels, hydrogen, hydrological resources, solar energy, wind energy, biomass and geothermal. Secondary energy includes electricity and heat.

Useful energy is not included, since there is no data specific for Aragón. Therefore the system boundary includes until final energy demand, which is the energy that the final consumer pays.

The geographical boundaries are Aragón limits. However, 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, there would be two periods in each scenario: first period until 2020 and a second period until 2030. According to the DGA, 2020 is considered the next checking point at European levels, and there is already different goals proposed. Therefore it seems logical to have a virtual boundary in 2020 where real policies and data can be easily found. The second period of time will allow more important changes in the energy system.

In the simulations, and more in general in the part of the thesis studying the future, electrical grid issues are not included. Gas natural and oil products grids are not considered either. Their importance in the energy planning is understood, however it is not the aim of this thesis to study or forecast grid needs.

Important limitations arise when studying the transportation sector. Due to data and time 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.

Land use is not included in this study.

2 Background

2.1 Logistic curve

There is empirical evidence that confirms that the development of technologies follow an S-curve, also called logistic curve. Figure 2 shows a typical S curve. In the X axis the market share of the technology is represented. Examples of market share measurements are installed capacity for electricity generation or number of cars that use biofuels. In the Y axis a measurement of performance vs. cost is represented. A higher value in the Y axis means a lower cost of the technology, a better performance, or both of them.

The X axis can also represent time in other representations of the S curve. When time is represented in the X axis, the Y axis shows the relation between performance and cost or the market share. In this study the logistic curves will represent time in the X axis and market share in the Y axis.

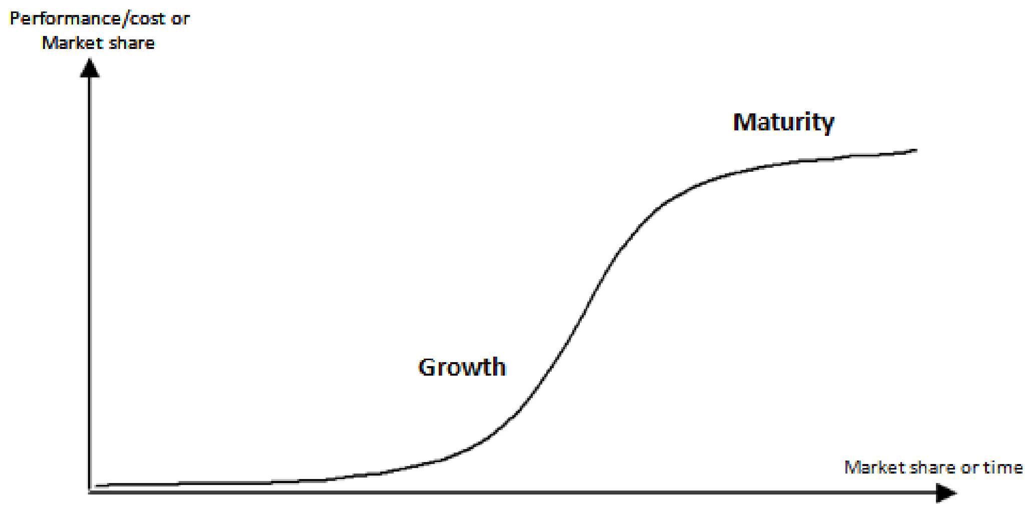


Figure 2. *Logistic curve representing the relation between performance/cost and scale of the technology. Source: Modified from Understanding the carbon lock-in (Unruh, 2000)*

Thus, 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.

Since the electricity generation is already mature, it is expect to be in the decreasing returns area, where the growth is more predictable. Besides, this concept is also useful to build the future scenarios. New technologies, such as solar PV or electric cars, will emerge in the next decades in order to decrease the CO2 emissions, and they will do it following the S-curve.

2.2 System approach, history and Reference Energy System diagram (RES-diagram)

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 connecting part is important and has a function. This means that the system is more than the sum of the different parts. The system approach focuses on studying the whole system instead of only the different parts, trying to understand also the relationships between the parts.

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 3 a simplification of the socio-technical energy system is represented.

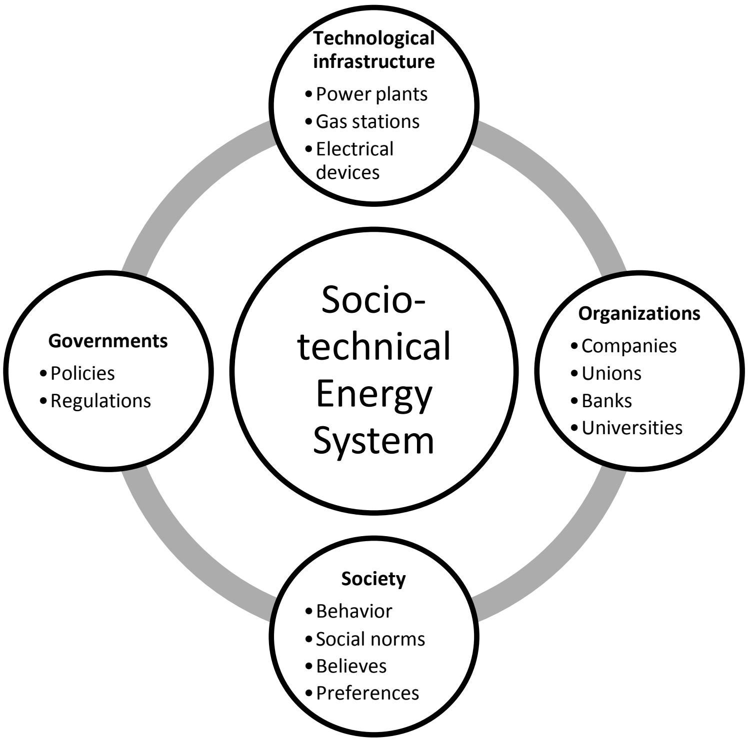


Figure 3 *Parts of the socio-technical energy system. Source: own elaboration from the theory in (Unruh, 2000)*

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. The positive feedback explained in Section 2.1 affects all parts of the system, not only the technology. 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).

The carbon lock-in is present both in the transportation sector and in electricity generation. Departments and ministries responsible of climate change issues were created to expand the fossil-fuel based society, together with laws and subsidies. People work in industries that rely in fossil-fuels use. Everyday life is dependent on fossil fuels. Universities teach the dominant technologies (Unruh, 2000). Hence, this is a very important issue to take into account when looking in to the future, and can only be understood analyzing the history.

Once that the evolution of a system is understood, the system has to be described at a point of time. 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 Reference Energy System diagram (RES-diagram) plays its role. A RES-diagram 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 a RES-diagram, showing how parts of the system are linked.

The RES-diagram of Aragón in 2008 is the input data to simulate the future scenarios. It also helps to understand the system and its behavior. The duration curve is another model that is necessary to study the system in LEAP. A duration curve represents number of hours of the year and the power dispatched. It allows organizing the different technologies as base or peak load (or in between).

3 Method

As explained before, the master thesis work is divided in two parts: historical analysis and future scenarios. The historical analysis consists mainly in a literature review, gathering data and identifying main components and development of the system. Also a simple program was used to calculate the logistic curve. In the second part LEAP is used to simulate the different scenarios and Excel to build the RES-diagram.

3.1 Data

Aragón has most of its energy data available online or in books.

3.1.1 Historical energy data

In this part, the most important quantitative data are installed capacity and electricity production. Is also necessary to know other types of historical data, as for example which companies did operate in the region, where, what was the electricity used for, etc.

The main sources of information are:

- *ERZ (1910-1990). El desarrollo del sector eléctrico en Aragón (Germán, 1998)* . This book tells the history of Eléctricas Reunidas de Zaragoza (ERZ). There is quantitative data available from 1901, although not in a regular basis until 1944. Despite of it, history, lists of companies and some economical results are available from the end of the 19th century. Therefore this book is the basis for the historical analysis until 1985.
- *Estructura energética de Aragón. Los balances energéticos regionales en el periodo 1984-1997(DGA, 2000).* Study that encloses extensive data and RES-diagrams from year 1992 to 1997. The period from 1984 to 1992 is excluded due to changes in the way of working in the DGA.
- *Los balances energéticos regionales en el periodo 1998-2004. Datos y análisis para una estrategia energética (DGA, 2005a).* Report used by the DGA as input for their last energy plan. It contains detailed data and explanations of different technologies, natural resources and energy uses.
- Energetic Reports of Aragón published every 6 months from 1998 by the DGA.
- Reports, regulations and governmental documents are used to provide basic information about regulation, taxes and prices. All this documents can be found in internet.
- Instituto Nacional de Estadística (National Statistical Institute, INE from the Spanish name) and Instituto Aragonés de Estadística (Statistical Institute of Aragón, IAEST from the Spanish name). Both institutes' web pages were consulted for demography and other data.

3.1.2 RES-diagram data

The Energetic Report of Aragón published in September 2009 contains the RES-diagram made by the DGA and data about the energy system in Aragón with different levels of detail.

This bulleting is available online (DGA, 2009b). The Excel document that was used by the DGA to calculate the RES-diagram and publish the bulletin was provided by Sergio Breto (DGA, 2009a).

3.1.3 Data needed to develop scenarios

Demographic forecasts can be found online in the Instituto Nacional de Estadística webpage (INE, 2010). The rest of the data needed to create scenarios are estimated based on historical analysis and existing reports. Three different reports have been used in short term forecast, and four in long term forecast. Recent news and governmental announcements are also considered. The seven used reports used are explained bellow:

- *Plan Energético Aragonés 2005-2012* (DGA, 2005b) is used as a reference. However, as the time period is longer in this study, other sources are needed.
- *Avance del informe del sistema eléctrico español, 2009* (REE, 2009). Preview of the Spanish electrical system yearly report for 2009. Data available in this report include: capacity changes in 2009, expected changes for combined cycle until 2011 and coal thermal until 2010.
- *Informe macro sobre la demanda de energía eléctrica y gas natural, y su cobertura (CNE, 2009).* Report about electricity demand and natural gas and their supply. Includes expected changes in hydro until 2013, as well as other technologies considerations.
- European forecasts are available in the report *European Energy and Transport – Trends to 2030. Update 2007 (Prof. P. Capros, 2008)* which will be called DG TREN in this report.
- *Europe's Share of the Climate Change* (Charles Heaps, 2009) uses DG TREN forecasts, and update them, to generate scenarios for Europe and each European country. It also uses LEAP. The authors of the report were contacted and provided data information.
- *Prospectiva de generación eléctrica 2030* (UNESA, 2007). Electricity generation forecast that introduces the point of view of the Spanish companies.
- Acuerdo político para la recuperación del crecimiento económico y la creación de empleo (Ministery of Economy and Treasury, 2010a). Political agreement for the recovery of economical growth and employment creation. This document includes a proposal of energy mix in 2020 from the Spanish government.

For the Electric car scenario the main document used is called Estrategia integral del vehículo eléctrico (Ministery of Economy and Treasury, 2010b). The aim of the plan is to have 250 000 electric cars in Spain in 2014.

3.2 Logistic curve and RES-diagram

The logistic curve was calculated for historical production of electricity, demand and installed capacity in Aragón. An Excel based program provided by Chalmers University calculated the best fitting curve for the data provided using the Fibonacci method. The program provides also future growth of the system and the asymptote of the logistic curve.

Once the asymptote had been calculated, the same calculation was carried out with +5% and -5% the first calculated asymptote value. Thus a probable range of growth is obtained.

The RES-diagram will be built in Excel.

3.3 LEAP

The Long range Energy Alternatives Planning system (LEAP) is a tool that can be used to create energy models. The data structure is adaptable to the availability of them and requirements are relatively low. 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 has built-in calculations that will give results for energy parameters, environmental effects and cost-benefit analysis. It also allows the user to enter its own equations.

The procedure to use LEAP has been:

- Create the data structure. In order to do this data available was analyzed and organized in a hierarchical tree.
- 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.

3.3.1 Data structure

The tree structure used in LEAP is provided in Annex 1. The tree has four main branches: key assumptions, demand, transformation and resources. Each branch is explained in this section. For detailed information about specific data see Section 7.

Key assumptions branch contains basic parameters that are necessary for the calculations. Demographic data, economical data, final demands sorted by fuel and by sector, transportation sector data and technology shares of electricity generation are included. Units are freely set by the user. Data included in key assumptions is used in other branches and internally by LEAP to calculate the results.

Final demand is included in LEAP in the demand branch. Data is organized by sectors and by fuels. Therefore the overall demand for a sector is introduced and under it the part of the demand that is used by each fuel. This allows the analysis of the overall demand level by sector, fuel changes and efficiency changes. This approach was chosen instead of introducing data for each appliance or device for two reasons: data availability and interest of the results. Results are easier to understand and compare with previous historical data, so they can be more interesting to possible stakeholders.

In the transport sector in the demand branch, it was not possible to separate consumption from road and train transport. Thus, demand for cars, truck and train is calculated together. This is because diesel consumption data was not possible to split between train and road transport. However, it is know that electricity is only consumed in trains, while gasoline and hydrogen is used by cars, trucks and buses.

The transformation branch includes the energy sector from the distribution of electricity to the extraction of energy sources. It must be organized with distribution close to demand and production of primary energy in the lowest level, since the energy flows from down to top. Therefore in this study the order of the blocks is:

1. Distribution losses: it only includes electricity losses. The rest of the data is not available
2. Own use: it includes only own consumption of electricity. Own consumption of heat is included in the cogeneration block.
3. Heat generation: includes solar thermal, geothermal and cogeneration. Although heat in cogeneration plants is produced together with electricity, in the program this module is located outside electricity generation. The reason for this is that the main product of cogeneration plants must be heat, being electricity a secondary product. This characteristic is not possible to model when including the cogeneration block inside the electricity generation, and it could result in heat demand not being met.
4. Electricity generation: includes hydro, coal thermal, combined cycle wind power and solar PV.

Production of coal, hydrogen, biofuel or biomass is not included in this study.

The last main branch is called resources. It is an inventory of the resources used in the region, which includes both primary and secondary energy. This branch can be used to forecast resource depletion and land needed. In this study data about coal and renewable resources available in Aragón are introduced to guarantee that the energy demand is possible to meet with the available resources. However, an analysis of land use is not included.

4 Electric sector historical development

In this section, the development of the electric sector will be described. This is divided in 7 periods:

1. Before 1911. Creation of the first companies and ERZ, which was the main electrical aragonese company.
2. From 1911 to 1936. Expansion until the Civil War
3. From 1940 to 1960. Post-war period
4. From 1960 to 1975. Technological development
5. From 1976 to 1985. Oil crisis
6. From 1985 to 1998. Reorganization
7. From 1998 to 2008. Liberalization and new technologies: cogeneration, renewables and combined cycle.

Each period is explained, with a small summary at the end in list form. 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)*.

4.1 Before 1911

In Aragón, electricity was introduced in 1883, in Zaragoza, to provide lighting in some cafés. Until the 50s, the electrical sector was driven by private initiatives by engineers or noblemen. In the case of Aragón, some persons were involved in more than one of the different important companies that emerged. This is probably because there were few persons with the required knowledge or with the required money.

Two companies were created in 1883: Compañia Aragonesa de Electricidad (Aragonese Company of Electricity) and Electra Peral Zaragozana. Compañia Aragonesa focused on thermal power and Electra Peral in hydropower. Although the main propose of this new companies was to provide lighting, gas lighting was spread in the city and had an agreement with the city council for 50 years.

Foreign initiative was spread around Spain, with the purpose of spread their technology. Three names where important in Aragón:

- AEG representative in Spain (from Germany). Involved in the foundation of Compañia Aragonesa de Electricidad.
- Averly (from France). Involved in the foundation of Electra Peral. A company was established in Zaragoza to provide machinery, which still exists today.
- Tudor (from Germany). It provided batteries to Electra Peral. Later the company opened a factory in Zaragoza.

In 1901 two new companies are founded in Zaragoza: Fuerzas Motrices (Motive Forces) and Telemática (Telematic). Fuerzas Motrices joined Compañia Aragonesa and Electra Peral in 1904, and they provided electricity for the trams in Zaragoza. Meanwhile Telemática opened a calcium carbide factory in Huesca, next to their power plant. Finally, in 1911, the four companies united in Eléctricas Reunidas de Zaragoza (Reunited Electrics from Zaragoza, ERZ from the Spanish name). The company had around 9 580 kW capacity, almost all of it hydropower. Hydro power became dominant from this point until the 50s, since the technology to use lignite was not developed and Aragón has enough hydrological resources.

At the same time, some factories installed their own power plants to provide light, especially in Zaragoza. Those factories were mainly sugar refineries and producers of heavy machinery. So in 1910 there were 50 electrical companies registered, all of them with less than 500 kW of installed capacity.

Factors

- Foreign influence
- Electricity was considered fashionable

Actors

- Noblemen
- Engineers
- Foreign companies
- Self-producers

Technologies

- Hydro and Thermal, with dominance of hydro at the end of the period.

Demand

- Very low, mainly for lighting
- Concentrated in Zaragoza

Economy

- Private investors provided capital needed.

Energy Policies

- None

Technology development

- AC and electricity transportation allowed hydropower to become the main technology.

4.2 Until the Civil War (1911-1936)

This period was characterized by 3 events: stagnation and following growth of ERZ, development of local and district companies and installation of big Spanish groups to operate hydro power plants.

Until 1921, ERZ continued to operate as the four different companies did before. No reorganization or expansion was made, even when ERZ was allowed to provide city lighting in Zaragoza from 1915. The result was that the company's installed capacity was not enough to meet the demand. However, the benefits of the company grew.

After reorganizing and increasing the installed capacity in 1924, the company only increased production by increasing working hours of the power plants. Thus, ERZ did not solve the existing problems during this period. Due to this bad organization, production in some factories had to stop during 1921, 1922 and 1935.

Instead, ERZ focused on distribution, buying small companies or the electricity produced by them to sell it. During the 30s, ERZ signed supply agreements with several industries and electrical companies, mostly in Zaragoza. Distribution lines were improved. Eventhough the capital investment was high, the benefits were even higher.

During this period, several local and district electrical companies emerged in Aragón. Most of the new power plants had less than 50 kW capacity. Electricity was provided to small industries or towns where the natural resources allowed.

Nevertheless, the important growth was caused by companies from outside Aragón. Companies from Basque Country, Catalonia and Madrid installed big hydro power plants in the rivers at the Pyrenees. The aragonese owners of the river concessions sold the majority of them during the first decades of the 20th century, even if most of them where part in ERZ management. Therefore, these companies could produce their electricity in Aragón, where it was easy and cheap, and transport it to more industrialized areas. As a result, in 1934 18% of the Spanish electricity was produced in Aragón. Table 1 shows the most important companies generating electricity in Aragón in 1935 and the destination of the electricity. The most important companies delivering electricity outside Aragón where:

- Hidroeléctrica Iberica (Iberian Hydroelectric). Produced electricity in the central Pyrenees and delivered it to Bilbao. It was the biggest producer in Aragón at that time.
- Cooperativa del Fluido Eléctrico (Cooperative of Electric Fluid). Produced electricity in east Pyrenees and delivered it to Barcelona.
- Electro Metalúrgica del Ebro (Electric Metallurgic of Ebro, EMESA from the Spanish name). This company was located in eastern Zaragoza province, by the river Ebro. Next to the power plant a calcium carbide factory was installed. Therefore the company produced for the factory and delivered the rest of the electricity to Barcelona. A small amount was sold to ERZ
- Other small companies from Valencia and other parts of Spain.

Consumption was concentrated in a small number of important electro-chemical and metallurgical companies. Aragón was not very industrialized, but it was one of the main providers of electrochemical and metallurgical services for Spain, since electricity was cheaper. These industries were located mostly in Zaragoza. In the rest of Aragón, only a few important industries were installed, always close to hydrological resources and not in the traditional trading cities. The reason for this is that most of the capital was private from outside Aragón (online).

Regarding demand in households, it did not grow together with generation. However, it was common for the people to “steal” electricity. During the last years of the period, those thefts were estimated in around 40% of the electricity deliver in Zaragoza.

EMESA was one of the companies that came to Aragón to install an electricity intensive factory. More important was Energía e Industrias Aragonesas, S.A. (Energy and Industries from Aragón, EIASA from the Spanish name). The company was founded in Barcelona by a French Chemical group. The purpose was to use the hydrological resources in the river Gallego in chemical industries. But this time the industries remained in Aragón, in the small town of Sabiñanigo in Huesca. This town with 100 inhabitants grew and grew with new industries that came, since there was surplus of electricity. And when the surplus was used, more hydroelectric plants were built. In 1930 EIASA was bought by Banco Urquijo (Urquijo Bank), with headquarters in Madrid.

Table 1. Most important companies in Aragón in 1935. Source: own elaboration from (Germán, 1998).

Name	***Production (GWh)***	***Capacity (MW)***	***Electricity destination***	***Year***	***River***
Hidroeléctrica Iberica	167.67	97.8	Basque Country	1918	Cinca
EIASA	98.83	15.48	Self consumption	1921	Gallego
Cooperativa del Fluido Eléctrico	96.06	30.20	Catalonia	1914	Esera
ERZ	83.03	15.79	Aragón	1911	
EMESA	81.42	18.89	Catalonia (50%), self consumption, ERZ	1907	Ebro

Factors

- Inefficient organization of ERZ production.
- River concessions sold to people from different parts of Spain.
- Plenty of hydrological resources in the Pyrenees and in the river Ebro.
- Low prices of electricity

Actors

- For a list of the most important companies, see Table 1
- Companies from outside Aragón.
- Small local producers
- Energy intensive industries.

Technologies

- Hydropower.
- Very little thermal.

Demand

- Concentrated in Zaragoza and in energy intensive companies.
- Important amounts of electricity were exported.
- Demand in Aragón did not grow as expected.
- Electricity theft was common.

Economy

- Despite the unorganized situation of ERZ, the company increased profits
- Banks started to be involved in electricity companies.

Energy Policies

- None

Technology development

- Distribution lines were improved.

4.3 Post-war period (1940-1960)

4.3.1 Spain

The Civil War (1936-1939) did not seriously affect the existing energy infrastructure, but it caused a building halt. There were three factors affecting Spain. First, during the war and just after it, fuel was scarce. It was also difficult to obtain machinery and materials from abroad, and they were not produced in Spain. Second, until the 50s the government did not participate in the sector, neither encourage private initiative. And third, the price of the electricity did not change while the inflation was significant. As a result, there were restrictions on consumption from 1944 to 1953.

The companies answer to this situation was to create an association in 1944. UNESA was created in an attempt to organize and rationalize the electricity market without the state intervention. Spain was divided in 6 zones. Aragón was one of the zones, with two companies: ERZ and EIASA. Connection between different companies was therefore allowed and made easier. This was an important change in the market. In 1952 UNESA organized a centralize office to control de electricity system at national level. It also worked as a lobby.

In 1953, the Unified Price of electricity was introduced by the government. It was a fixed price for all the companies, regardless the cost of their production. This new price included subsidies for thermal electricity and for new power plants. The goal of the government was to increase the number of thermal power plants, since droughts in the country had decreased the electricity production.

At this point, the government had to act to solve the lack of electricity. As there were a number of companies in serious problems, the state bought them. The state also started several companies related to energy. From those, three affected Aragón:

- Empresa Nacional Calvo Sotelo (National Company Calvo Sotelo, ENCASO) in 1942. Energy was not the core of the company but it included the construction of three thermal power plants, one of them in Aragón.
- Endesa in 1944, to install a thermal power plant. Endesa will become the main energy company in the country.
- Empresa Nacional Hidroeléctrica Ribagorzana (National Hydro electrical Company from Ribagorza, ENHER) in 1946 to exploit the river Noguera-Ribagorzana, situated in Aragón and Catalonia.

4.3.2 Aragón

During the 50s, Aragón started to produce electricity in big thermal power plants, but most of it was consumed outside the region. Aragón lost its advantage of cheap electricity for industries when the Unified Price was stabilized. However, energy intensive industries continued to be important in the region.

Three new big companies were established:

- ENCASO: public sector played a major role in the new power plants. ENCASO built a thermal power plant in Zaragoza, called Escatrón, with 172.5 MW. This was around 45% of the new installed capacity in this period. The construction started in 1952 and ended in 1958. The energy was sent outside Aragón.
- ENHER: 48.4 MW of hydro power in Aragón, but the electricity was also use outside the region.
- Hidronitro: the company installed 27 MW of thermal power in Monzón, a town in the province of Huesca that had a similar development as Sabiñanigo. Electricity was all consumed by the new factories, also own by the company. The first power plant started operation in 1949.

The two aragonese companies already in operation, ERZ and EIASA, also built new facilities. ERZ main action was Aliaga, a 46 MW thermal power plant situated in Teruel. Aliaga was build 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.

ERZ shows a great expansion during this period. Starting in Zaragoza province, at the end of the period it controlled most of the region. This was achieved buying small and medium companies all over Aragón. It is during this period that Caja de Ahorros de Aragón, Zaragoza y la Rioja (Savings Bank from Aragón, Zaragoza and La Rioja, CAZAR), which was the main bank in Aragón, became involved in ERZ. Not only CAZAR provided loans to ERZ, but also the director of CAZAR was elected president of ERZ in 1952.

The main characteristic of the electricity market in Aragón was that different companies were the main producers and the main distributors of electricity. This was consequence of the implantation of companies from other regions before the Civil War. Table 2 shows the main producers in Aragón, and

Table 3 the main distributors.

Table 2. Main electricity producers in Aragón in 1956. Source: own elaboration from (Germán, 1998)

Company	***Production (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	1326	71,7 %	426	70,4 %

Table 3. Main distributors of electricity in Aragón in 1959. Source: own elaboration from (Germán, 1998)

Company	***Distribution (GWh)***		***Area***
EIASA	273	40.2 %	Central Pyrenees
ERZ	272	39.9 %	Rest of Aragón
Total	545	80.1 %	

Factors

- Spanish isolation from the rest of the world.
- Implication of the state during the 50s.
- Lignite resources in Aragón.

Actors

For a list of the most important companies, see Table 2 and

- Table 3
- UNESA created in 1944.
- Energy intensive industries.
- CAZAR.

Technologies

- Coal thermal power plants.
- Hydropower.

Demand

- Around 50% of the electricity production was exported.
- Demand could not be met at the beginning of the period.
- Quantitative data not available.

Economy

- Money needed by ERZ to increase was provided by CAZAR.

Energy Policies

- Subsidies to thermal power plants.
- Unified price for electricity introduced in 1953.

Technology development

- Coal thermal grew from almost zero to around 30% of the electricity production.

4.4 Development of the electrical sector (1960-1974)

4.4.1 Spain

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. Subsidies for fuels to produce electricity are introduced, and the subsidies for thermal power maintained.

During this period, regional systems became completely connected, and Spain was connected to France.

The first nuclear plant was installed in 1968. However nuclear power has never arrived to Aragón.

4.4.2 Aragón

In Aragón, there was an important development of hydropower. Great hydraulic infrastructure was built. At the same time, consumption increased due to industrial development and domestic use. The increase in demand was a consequence of the Spanish economic growth. Electricity-intensive industries continued to expand in the region.

The impact of the huge dams constructed in Aragón cannot be considered positive. Apart from the jobs created during the construction work, there were mainly drawbacks for the region. Lands were inundated and whole towns had to move, not being compensated enough. However, in the lower parts of the rivers, water could be used more efficiently for agriculture. This added more inequities in the region, since Zaragoza would benefit from it.

Regarding distribution and supply, 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 were also important and represented during this period from 15% to 20% of the electricity consumption. The most important companies of this type where EIASA (central Pyrenees) and Hidronitro Española (Monzón). EMESA and some sugar refineries were important in Zaragoza province.

On the production, ENHER became the most important actor. This was achieved by building the biggest dam in Aragón and some smaller, all in the same river. ERZ constructed also hydropower plants and 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 (Thermo-electric from the Ebro).

A new company was created in Teruel, called Unión Térmica (Thermal Union). 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.

During this period ERZ becomes an important actor in the societal life in Aragón. ERZ had important relations with industries, savings banks, regional government and local governments. CAZAR, as started in the previous period, continued to have a representative in ERZ as head of the Board of Management.

Table 4 shows the main producers of electricity.

Table 4. Main producers of electricity in Aragón in 1974.

Company	***Installed capacity (MW)***	
ENHER	515	32.3 %
EIASA	240	15.1 %
ERZ	225	14.1 %
Termoeléctrica del Ebro	172.5	10.8 %
Unión Térmica	160	10 %

Factors

- Regional energy systems connected.

Actors

- For a list of the most important companies, see Table 4.
- Energy intensive industries.
- ERZ became important in societal life.
- CAZAR.

Technologies

- Coal thermal power plants.
- Hydropower.

Demand

- Domestic and Industrial demands increased.

Economy

- New pricing method introduced in 1970.
- ERZ continuously increasing capital.

Energy Policies

- Subsidies to thermal power plants.
- Subsidies to fuels used in electricity production.

Technology development

- Several big dams were built in the region.
- First pumped-storage plant built in Aragón
- Development of the distribution lines

4.5 The energy crisis (1975-1985)

4.5.1 Spain

The oil crisis affected Spain later than other countries due to the political situation. The delay made the effects of the crisis worse than in average countries. The first national energy plan (PEN from the Spanish acronym) was made in response to the oil crisis.

Three energy plans were approved during this period, one in 1975, a second one in 1978 and a third one in 1983. The fist plan included actions to solve the first oil crisis, and it was expected to be valid from 1975 to 1985. However, after Franco died, a revision for this plan was necessary and the new government made the 1978-1987 energy plan. But the demand forecasts were too high, so projects needed to be canceled, as well as gas contracts with providers. Although this plan was revised in 1982 a brand new government published another plan a year later, the PEN 1983-1992 (Mir, 1999).

The main goals of the PEN-78 was to substitute oil in the production of electricity by carbon, to support hydropower and to cover the remaining demand with nuclear. This was changed with the PEN-83, were nuclear plants constructions were halted to adjust to the new demand predictions. In the same plan, the high voltage grid was nationalized and a new company was created to control it: Red Eléctrica de España (Spanish Electric Grid, REE).

Another 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, in 1980 a law for Energy Conservation came into force. The Energy Conservation law aimed in promoting self-generation and small hydropower, with less than 50 MW capacity. The foundations for the special regime are(UNESA, 2004):

- To be able to connect the power plant to the distribution network.
- The distribution company has to buy the electricity surplus.
- The electricity price is fixed in order to encourage this type of installations.

In general, the electrical companies increased their debt, due to the bad economical situation in the country. The PEN-83 included this situation and increased the control that the government had over the companies through compulsory audits, common funds, compensations and suspension of unnecessary inversions (Mir, 1999).

During this decade the electricity prices increased continuously to cover fuel cost, inflation and other costs. A fee was included in the electricity price to compensate the areas with big power plants. In 1986 this fee disappeared when VAT was introduced in Spain.

4.5.2 Aragón

During this period Aragón had a similar development to Spain. The main change was the increase in the use of coal. As coal was important to substitute oil, a new thermal power plant with 1050MW capacity was built by ENDESA in Teruel, called Central Térmica Teruel (Thermal Power Plant Teruel, C.T. Teruel). At the same time the use of old mini-hydro power plants increased.

Regarding companies, ENDESA became the most important electricity producer after building C.T. Teruel. ENHER remained the second company with more capacity installed after constructing several new hydro power plants. Table 5 shows the most important electricity producers in Aragón. Notice that ERZ disappear from the list, since during this period it only had 6% of the installed capacity.

ERZ focused completely on distribution. The thermal power plant in Aliaga was closed in 1981 and Escatrón decreased in capacity due to environmental restrictions. Therefore ERZ had to sign several contracts to buy energy from different companies, first with ENHER and lately with Iberduero, until REE controlled the system in 1985. ERZ ended this period with loss.

Table 5. Main electricity producers in Aragón, year 1985

Company	***Installed capacity (MW/%)***	
ENDESA	1050	38
ENHER	761	27.6
EIASA	292	10.6

A number of improvements were made in the electric grid by ERZ and the state, but the most important change was in the natural gas grid. The developments in the natural gas grid during the last 5 years of the period allowed an increase of the natural gas consumption in the region.

CAZAR continued to cooperate with ERZ in finance issues and by having a person in the Board of Management. At the same time, members of boards of management of different companies in Spain will change from one to another.

Factors

- Oil crisis delayed.
- Government encouraged of both coal and hydro.
- Environmental restrictions affected old coal power plants in Aragón.

Actors

- For a list of the most important companies, see Table 5.
- REE.
- ERZ, only distribution.
- CAZAR.

Technologies

- Coal thermal power plants.
- Hydropower, both big and small scale.

Demand

- Demand decreased during the second half of the period due to delayed effects of the oil crisis.

Economy

- Increase of debt.
- Electricity prices increased.
- Fee to compensate areas with power plants.

Energy Policies

- Three energy plans: 1975, 1978, 1983.
- Nationalization of the high voltage grid.
- Government increased control over the companies.

4.6 Before liberalization (1986-1997)

4.6.1 Spain

In 1986 there was a reorganization of the Spanish electricity market. The goal was to equilibrate the market and the companies. The structure of some companies was not appropriate. For example, offer did not correspond with demand. There were also discontinuities in the market due to poor territorial division. This situation was solved with an asset swap.

A key event in this period is the incorporation of Spain to the European Union. In order to become part of the unique market, there was a need to have powerful companies. So from 1991 a new reorganization was made. As a result, four big companies were created. Endesa was one of them, the only one with state participation (UNESA, 2004). The government's goal was to create stable big companies, and maintain them Spanish to facilitate control Arocena et al., 2002).

Besides, the prices were also controlled by the government. Electricity price was calculated using in "standard costs". Each element needed to provide electricity was assigned a standard cost, and the final consumer price was calculated dividing the total standard cost by the expected demand. There were different tariffs depending on type of use and amount of electricity use. Thus, this system encourages the companies to reduce actual costs (Arocena et al., 2002).

To face the changes that had undertaken and were expected in the energy sector, the government carried on a new national plan, PEN 1991-2000. The plan had four main goals: to minimize cost, to use national resources, to protect the environment and to diversify. A secondary goal was to increase self consumption and renewable energy (UNESA, 2004).

Following the PEN-91, a new law to regulate the national electrical system was introduced in 1994. This law aimed to develop the system according to European rules and at the same time following the national market directions (DGA, 2000).

Also 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
- Cogeneration
- Waste to energy
- Biomass
- Renewable energy (new plants)
- Plants that use waste heat

Distributers of electricity were forced to buy electricity from those types of power plants if they had less than 100 MW (Spanish National Energy Comision, 2010), except from hydropower were the limit was 50 MW.

4.6.2 Aragón

As ERZ had an unbalanced situation, the company became part of the ENDESA group, together with ENDESA, ENHER and other Spanish companies. The financial difficulties of ERZ were solved. After becoming part of ENDESA, ERZ specialized even more in distribution.

With the new reorganization, classification regarding companies lost its importance. The main group operating in Aragón is ENDESA, but the previously existing self-producers remained. According the study Energy Sector Structure in Aragón (Aragón, 2000), there were three companies distributing energy in Aragón during this period: ERZ, ENHER (both in the Endesa group) and Electra del Maestrazgo.

The efforts made by the government since 1980 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 with 360 kW capacity. The project was a collaboration between ERZ, ENDESA, the regional government and the Institute for Diversification and Savings of Energy (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 coal combustion. It became part of the regulated system in 1996.

The first regional energy plan was made in 1994, as well as a number of studies about energy in Aragón.

Factors

- Complete reorganization of the sector.
- Spain becomes part of the European Union.

Actors

- ENDESA.
- ERZ, as a part of ENDESA.
- ENHER, as a part of ENDESA.
- Electra del Maestrazgo
- Auto-consumers.
- Regional Government
- IDAE, supporting renewable energy.
- Actors at national level

Technologies

- Coal thermal power plants.
- Hydropower, both big and small scale.
- Cogeneration, some with biomass.
- Wind power.
- Other renewable energies in a minor extent.

Demand

- Demand recovered.

Economy

- Recovery of the companies via the reorganization.
- Prices calculated using "standard cost"

Energy Policies

- PEN-91.
- Definition of the special regime.
- Regional Energy Plan in 1994.

Technology development

- Fist Spanish cogeneration plant installed in a paper factory in Zaragoza.
- Biomass used in cogeneration.
- Wind power demonstration projects.

4.7 Liberalization of the sector and renewable energy (1998-2008)

4.7.1 Spain

Liberalization of the energy sector was necessary in order to meet European requirements. So the Electrical Sector Law was made in 1997 to carry on the liberalization. The state traditional planning capacity changed. Now each company will decide what to install, while the government can only decide about transportation lines and administrative issues. There is also freedom to buy and sell electricity in other EU countries, as well as to access transportation 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: transport and distribution
- Not regulated activities: generation and commercialization.

According to UNESA, there are six main actors in the Spanish electrical sector from the liberalization of the market:

- Producers in ordinary regime.
- Producers from special regime. All the electricity they produce must be introduced into the system.
- External agents from systems outside Spain.
- Distribution companies
- Commercialization companies
- Consumers
- Management authorities: Market Operator (economical management) and System Operator (technical management). REE runs the market in a daily basis.
- Regulation authorities: Spanish Government and the National Commission of Energy (CNE). The regional government also plays a major role.

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 produce every hour of the following day. Then REE balances demand and production according to prices. The price of electricity is the price of production of the last plant needed to cover the demand.

Electricity tariffs are equal in the whole country, except for "qualified consumers" that could negotiate their contracts. The tariffs included 5 terms(CNSE, 1997):

- Production cost, determined according to the average kWh price during a fixed period. It can be changed independently.
- Tolls for transport and distribution.
- Commercialization cost.
- Permanent cost of the system. It includes cost of the Electrical System National Commission (CNSE), cost of the system operator and market operator, and cost of electricity supply in extra peninsular Spanish territories that cannot be afforded by those territories.
- Diversification and security of supply costs.

The government can 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
- Chose the Last Resource Tariff (TUR). TUR is decided by the government and equal in all the 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).

However, major differences between planned and real installed capacity of solar PV and wind power made it necessary to change the renewable regulation, according to the government (B.O.E., 2008). Therefore new tariffs and a capacity cap were introduced for solar PV in 2008, and a mandatory registry for special regime installations came in force in 2009, with new caps for wind and solar thermal 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).

Other important plan regarding sustainable energy is the Renewable Energy Plan (PER 2005-2010). The PER 2005-2010 had three main goals by 2010: 12,1% of the total primary 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 (IDAE). The PER 2011-2020 is under development.

At the same time, combined cycle has become an important technology in Spain. One of the major concerns is the high energy intensity, both in Spain and Aragón (DGA, 2005a). As combined cycle has a better efficiency, is an interesting technology to decrease energy intensity. Renewable energy and decrease of the demand are also important points to achieve better energy intensity.

4.7.2 Aragón

There are two important technologies during this period in Aragón: combined cycles and wind power.

Wind power is the main character during this period in Aragón. There was 137 MW installed in 1998, which grew to 1 712 MW in 2008. There are three reasons for this increase: good legislation, development of the technology, and excellent wind conditions (DGA, 2005a). Currently wind power is the second technology with more capacity installed in Aragón (DGA, 2009a)

Today the technology with more installed capacity is combined cycles (CC). From not existing in 2005, at the end of 2008 it had 1 781 MW installed (IAEST, 2009). As explain before, CC is interesting to decrease energy intensity. It also benefits the environment if it substitutes coal or oil fired power plants.

Cogeneration was expected to grow more than it has done. From 327 MW in 1998, in 2000 there were 445 MW and in 2008, 553 MW. The reason for this was the uncertainty in fuel prices and the changing prerequisites necessary to install a cogeneration facility (DGA, 2005a).

Solar energy is not relevant yet. It is worth noticing that around 100 MW of solar PV where installed during the year 2008 (DGA, 2009b). However, due to the new regulations and caps, this growth is not expected to continue.

Regarding energy planning, there have been 4 main documents during this period:

- Regional Energy Plan 1994-2013 (PEA)
- Renewable Energy Action Plan in Aragón 1998-2005 (PAERA)
- Evaluation Plan for the Special Regime in Aragón 2000-2002 (PEREA)
- Regional Energy Plan 2005-2012

PEA and PAERA were forecasts of installed capacity, production and demand. PEREA focused on special regime and determined the capacity to install taking into account transport grids. Due to changes in technologies, especially wind and CC, a new Regional Energy Plan was carried out. A shorter period of time was considered in it in order to be able to adjust the planning process to changes in the system (DGA, 2005b).

Factors

- Liberation of the sector.
- Environmental concerns.
- Good renewable resources.

Actors (DGA, 2009b)

- ENDESA.
- Iberdrola.
- E.ON.
- Electra del Maestrazgo
- Auto-consumers.
- Regional Government.
- Actors at national level.

Technologies

- Coal thermal power plants.
- Hydropower, both big and small scale.
- Cogeneration, some with biomass.
- Wind power.
- Combined cycle.
- Solar and other renewable energy in a minor extent.

Demand

- Demand continued increasing.

Economy

- Regulated tariffs until 2009, after that TUR or negotiation with a commercialization company.

Energy Policies

- Feed-in tariffs and PER 2005-2010.
- Regional Energy Plan 2005-2012

Technology development

- Cogeneration development halted.
- Wind power becomes the second technology in installed capacity.
- CC appears and becomes the technology with highest capacity installed.

4.8 Electricity generation technologies evolution from 1992 to 2008

In this section the evolution of the electricity transformation sector is explained in detail from year 1992 to the 2008. Year 1992 was chosen as a starting point because it was the first year in which heat from cogeneration was included as separate data, and renewable energy separated in different sources.

There are six technologies that generate electricity: coal thermal, cogeneration, combined cycle, hydro power, wind power and solar PV. Figure 4 shows the evolution of installed capacity for the different generation technologies present in the region. Electricity generation by technologies is shown in Figure 5. Figure 6 illustrates the equivalent working hours for each technology. Finally, Figure 7 represents the situation in 2008. These four figures are explained bellow.

Coal thermal in combination with hydropower have traditionally been the most important technologies. Hydropower is divided in special regime and ordinary regime, as explained in section 4.6. Most of the hydropower capacity installed in Aragón is ordinary regime and is located mainly in Huesca province. Regarding coal thermal power plants, there are three in Aragón: Escucha, Teruel (both of them in Teruel province) and Escatrón (in Zaragoza). However during year 2008 the thermal power plant in Escatrón did not produce electricity.

Coal and hydro power installed capacity has remained approximately constant, but due to the increase in total installed capacity their share decreased from 46% to 20% for coal thermal and from 52% to 22% for hydro power. To generate electricity, more coal thermal was used in dry years, although it was explained before that coal thermal electricity generation was more dependent on national strategy. In year 1992 hydropower represented around 30% of the electricity generation, while coal thermal represented a 65%. Nevertheless, in year 2008, hydro represented 15 % and coal thermal 25% of the total electricity generated in the region. Although both technologies fluctuate, their evolution trend is approximately constant. However, coal thermal has decreased its production since 2005, and in year 2008 it generated 19% less electricity than in 1992. Data for year 2009 in Aragón is still not available, but national data indicates that coal thermal production has decreased to a minimum after 2008 (REE, 2009)

These changes are caused by the introduction of new technologies, explained in Sections 4.6 and 4.7 and observed in Figure 4, Figure 5 and Figure 6: growth of cogeneration, then wind power, and later CC. Cogeneration has increased its share from 2% to around 8% of the total installed capacity in Aragón. Average yearly increase of cogeneration installed capacity is 12.6%, with a maximum of 89% from 1992 to 1993 and a minimum of -4.5% from 2007 to 2008. Electricity generated in cogeneration plants had an important increase from 5% of the total electricity generation in 1997 to around 18% in 1998. After 1998 the increase in generation has not been as important, and in year 2008 it represented around 15% of the electricity produced. The heat production from cogeneration in 2008 was 4 187 GWh, more than 99% of the final heat final demand in the region (note the difference with useful heat demand).

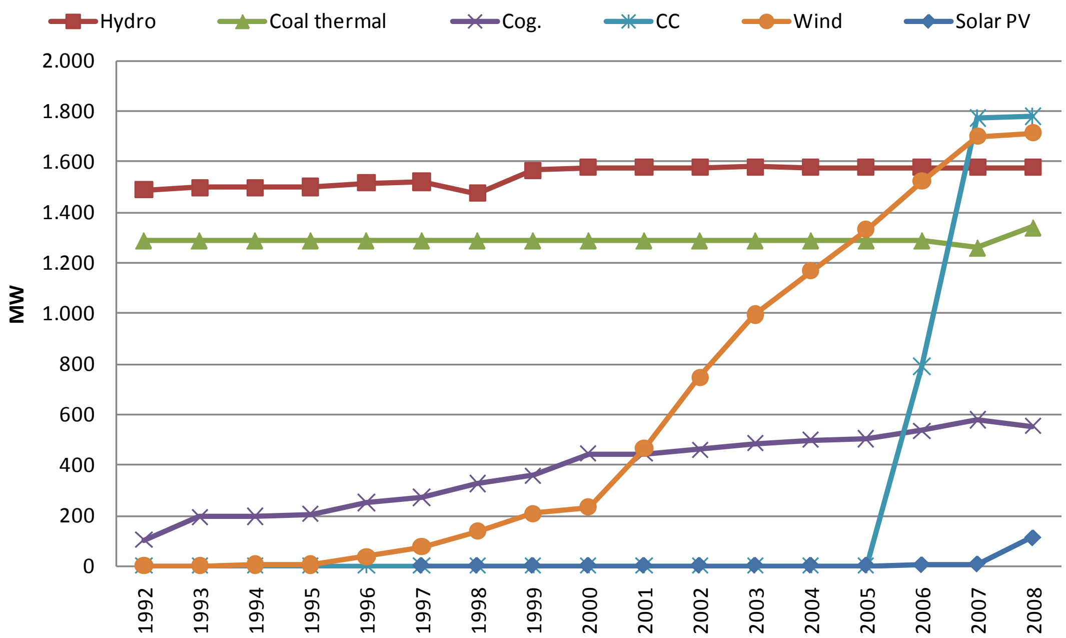


Figure 4 *Installed capacity for the different generation technologies from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)*

Next technology that was introduced is wind power. Most of this installed capacity is located in Zaragoza, since it is the province with more wind potential. Wind power has in 2008 around 25% of the total installed capacity. Average yearly increase is 111%. However, from 2001 the yearly percent growth has decrease. While in 2001 it was 100%, in 2003 it was 30%, in 2005 14% and in 2008 0.8%. This is because of problems that are caused by wind technology, such as intermittence, lack of electrical grids to evacuate the electricity, etc.

Another reason is that the best locations to place wind farms are already occupied. As for electricity generation, wind power had a negligible share in generation capacity in 1992, while in 2008 it generates around 18% of the electricity in the region.

Finally, CC first power plant started operation in 2006 with 791MW which accounts for 14% of the installed capacity in that year. The share of CC in the installed capacity grows to 25% in 2008. Today CC is the technology with more capacity installed and more production. In 2008, CC represents 26% of the electricity produced, slightly more than coal thermal. There are three CC plants in Aragón, two in Zaragoza and one in Teruel

These three "new" technologies together represent around 60% of the electricity produced in Aragón in 2008.

It is important to notice the evolution of solar PV, even if its share in the electricity generation is still less than 1%. From year 1997 to year 2000 installed capacity grew always above 45% every year. From 2001 to 2005 this increase was stagnated around 30%. Nevertheless, from 2005 the yearly increase has been more than 100%, and in 2008 the installed capacity multiplied by more than 18. Electricity generated from solar PV has increased yearly always above 13% from 1997. In average, electricity produced by solar PV is multiplied by 2.6 every year. However, this average is very influenced by the maximum increase. From year 2007 to 2008 solar PV electricity generation increased from 5 GWh to 122 GWh. If this data is not included, the average yearly increase is 51%.

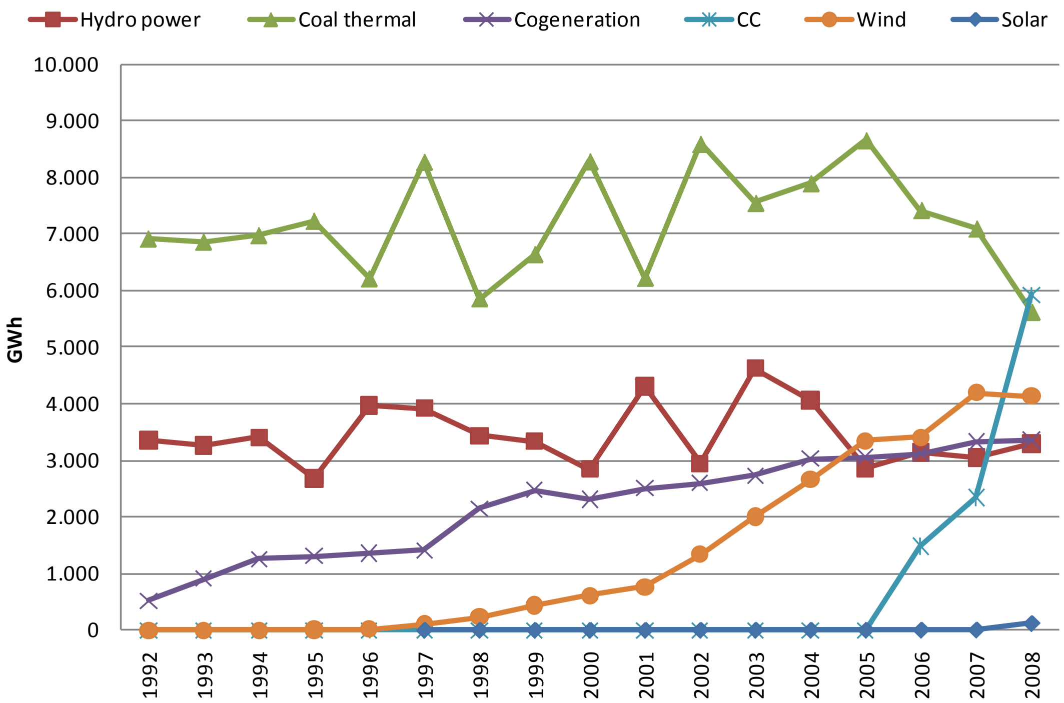


Figure 5 *Electricity generation by technology from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)*

Figure 6 shows the equivalent working hours for each technology, calculated as in equation (1). The first characteristic of Figure 6 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. This is an important difference between generation technologies: wind power and solar energy cannot be managed as coal thermal 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 that installed capacity.

$$h_{eq} = \frac{Electricity\ generation\ [MWh]}{Installed\ capacity\ [MW]} \quad (1)$$

All technologies have an approximately constant value of the equivalent hours. 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.

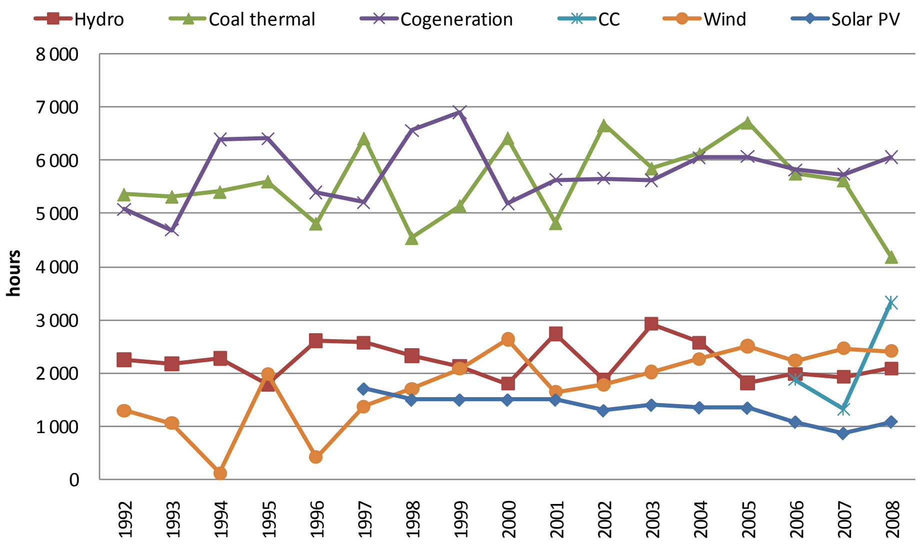


Figure 6 Equivalent working hours for each technology from 1992 to 2008. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)

Regarding fuels 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. In the case of CC power plants, only natural gas is used.

Coal thermal power plants use both local coal and imported coal, since local coal has not good environmental and energy quality. The amount of coal imported that is used depends on national strategies and prices. From year 1992 to 2008 the share of imported coal has been in a range from a minimum of 15% in 1998 to maximum of 61% in 2002. These years coincide with a minimum and a maximum respectively of electricity produced by coal thermal power plants. Although the main fuel consumed is coal, coal power plants also consume small amounts of diesel and natural gas for start up.

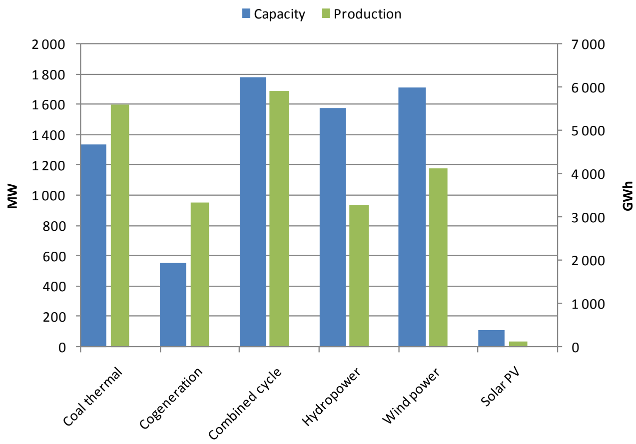


Figure 7 *Installed capacity and electricity production by technology in Aragón in 2008. Source (DGA, 2009a, DGA, 2009b, DGA, 2009c)*

Regarding fuel use in cogeneration facilities, Figure 8 shows the evolution in the use of the different fuels form 1992. Natural gas has increased in more than 700 GWh from 1992, although its contribution in the fuel share has decreased from 96% in 1992 to 88% in 2008. The second most important fuel is biomass. Biomass utilization in cogeneration had and important growth from 1997 to 1999, when the biomass used was multiplied by 10. The share of biomass in used fuels in cogeneration was 2% in 1992 while in 1999 it grew to 15%. From 1999 the use of biomass is approximately constant. Therefore its contribution to the fuel share has decreased to 10% in 2008. Oil products (fuel oil and diesel) started to be used in year 1996. Their contribution rose until 2000, when they represented 5% of the fuel used. From 2000 their utilization has decreased and in 2008 oil products represented 1% of the fuel share. Finally, there is a very small amount of waste products use in cogeneration plants. Waste represents less than 1% of the fuel used in 2008

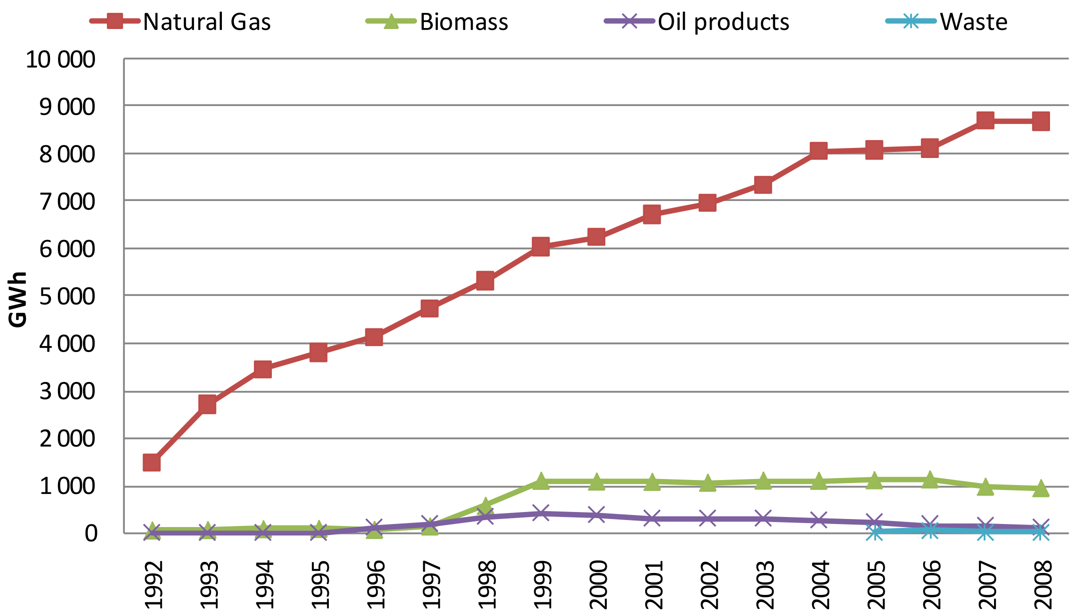


Figure 8 *Fuels used in cogeneration facilities. Oil products include fuel oil and diesel. Source: (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)*

5 Logistic curves

In this chapter the results from the logistic curve program will be presented. It will show the forecasts, but also an overview of the evolution of electricity production, consumption and installed capacity explained in section 4.

5.1 Consumption

Figure 9 shows the electricity consumption in Aragón from 1959 and the calculated logistic curves. Analyzing the historical evolution, 3 periods can be distinguished:

1. From 1959 till 1979: electricity consumption increases. It corresponds to a period of economic growth in Spain.
2. Early 80's: demand decreases because of delayed effects of the oil crisis.
3. Late 80's till today: demand increases steadily. From year 2000 the growth rate is higher, also due to general economic growth.

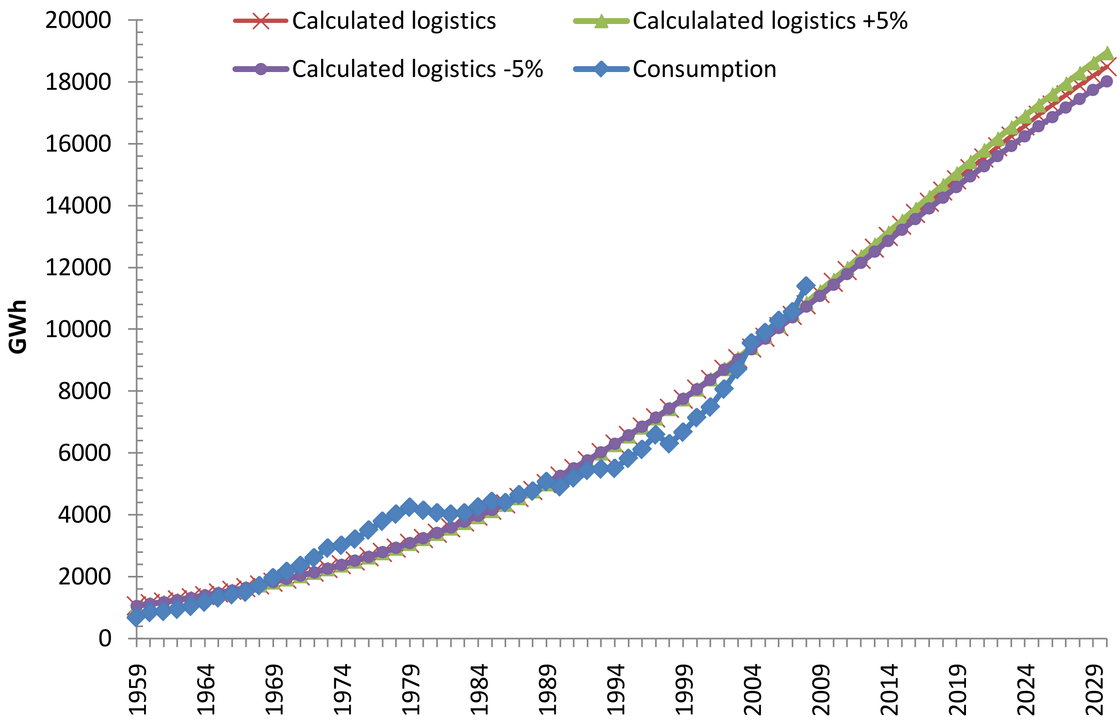


Figure 9 Electricity consumption from 1959 to 2008 and logistic curve until 2030.Source: own elaboration.

The asymptote for the logistic curve is 25 632 GWh. However, the 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 Figure 10 the average percentage growth for every 3 years is represented, together with the calculated logistic curve. The three periods can also be observed in this curve. The calculated asymptote is 1.4%.

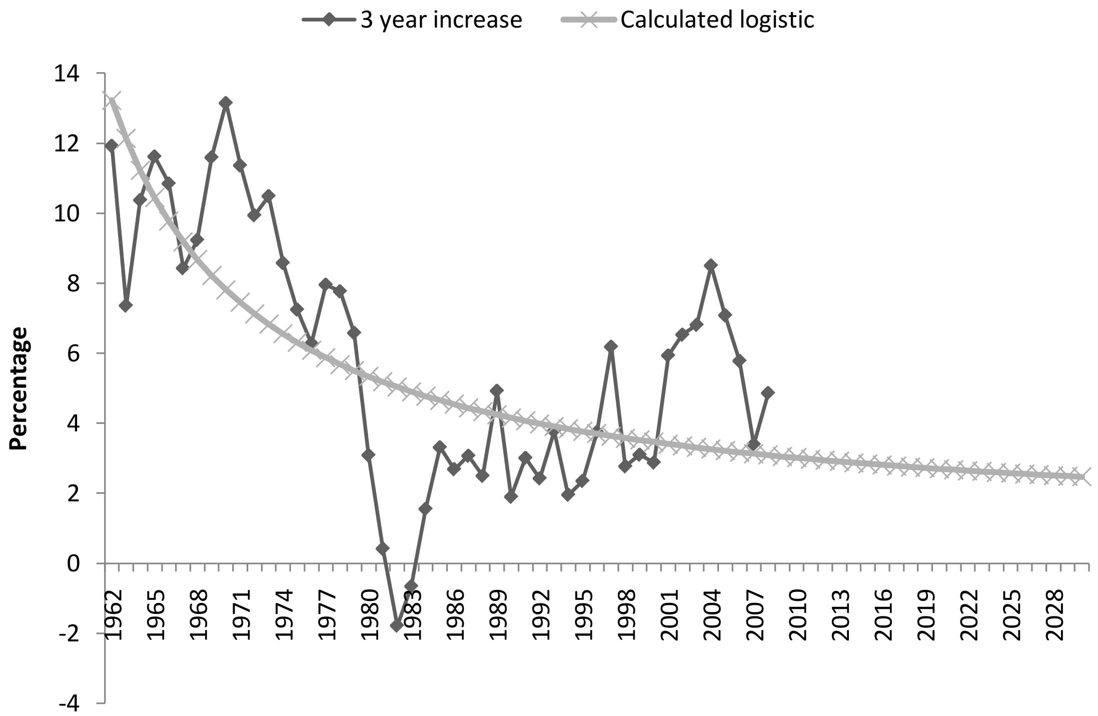


Figure 10 Three year increase of electricity consumption from 1959 to 2008 and logistic curve until 2025. Source: own elaboration.

5.2 Installed capacity

Analysing the installed capacity curve is easy to see the different power plants and technologies installed. Figure 11 shows the evolution of the capacity installed and the calculated logistic curves, where several events can be identified:

- From 1950 to 1958: installation of Escatrón and Aliaga.
- From 1963 to 1964: increase of hydropower.
- From 1968 to 1970: Escucha thermal power plant starts operations.
- From 1978 to 1980: C.T. Teruel thermal power plant starts running.
- During the 80's: Aliaga closes and Escatrón decreases capacity until it closes in 1988
- During the 90's: slow growth of cogeneration and wind
- From 2000 to 2008: installed capacity of wind power increases continuously, in more than 1 500 MW. From 2006 CC growth is easily recognized in the curve, with more than 1 770 MW installed in 2008.

As the electricity consumption, the installed capacity is also in the growth part of the logistic curve. 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.

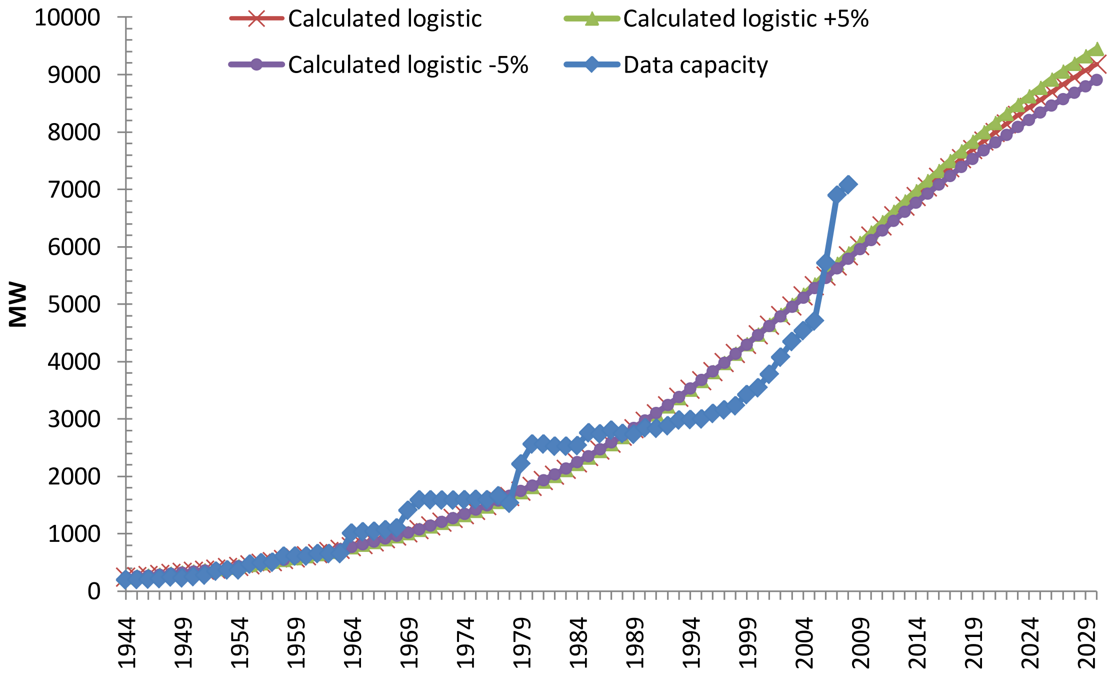


Figure 11 *Installed capacity evolution from 1944 to 2008 and logistic curve until 2030. Source: own elaboration.*

Average percentage growth for every 3 years and its logistic curve is shown in Figure 12. The different power plants installed are also identified. The calculated asymptote is 2%.

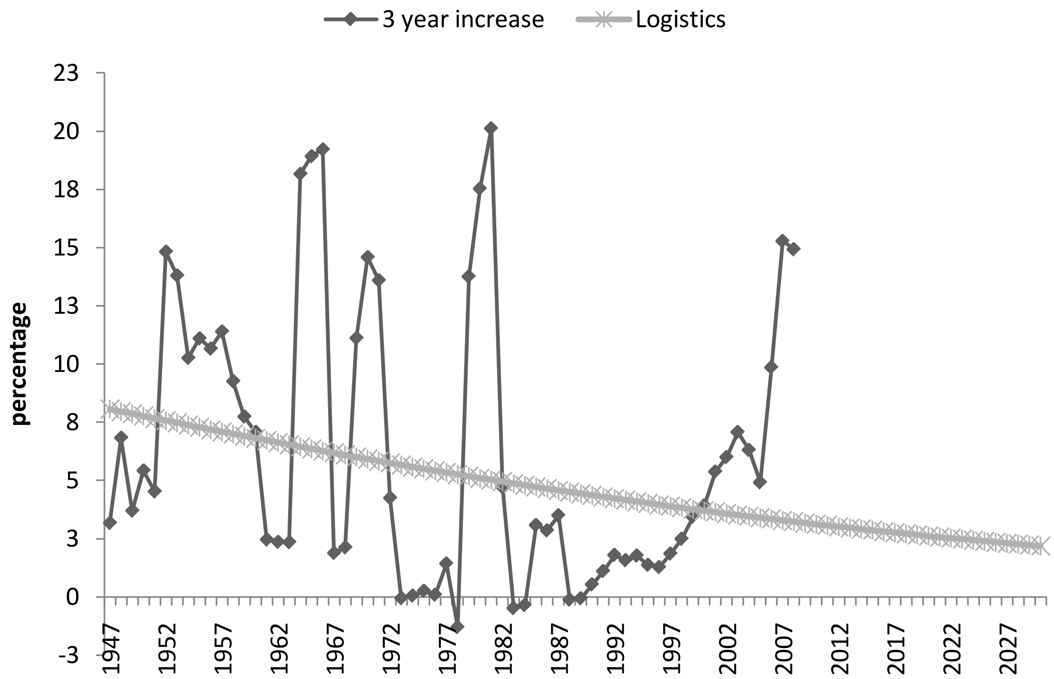


Figure 12 *Three years average increase of installed capacity from 1944 to 2008 and logistic curve to 2030. Source: own elaboration.*

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. For example, coal thermal and hydropower are very mature, while wind power and CC are not. 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 5089 MW.

5.3 Electricity generation

Electricity generation in Aragón has reached the maturity area in the logistic curve, as Figure 13 shows. The electricity produced in 2008 was 22 450 GWh, and the calculated asymptote is 23 871 GWh, only 6% higher.

This result seems contradictory to the result for installed capacity, which is still in growth phase. The reason for this surplus of installed capacity is the growth of CC, while coal thermal power plants still have the same capacity installed but produced less power. Renewable energy may also play a role in the decrease of electricity production from coal power plants. These relations are also explained in Section 6.1 and Figure 13.

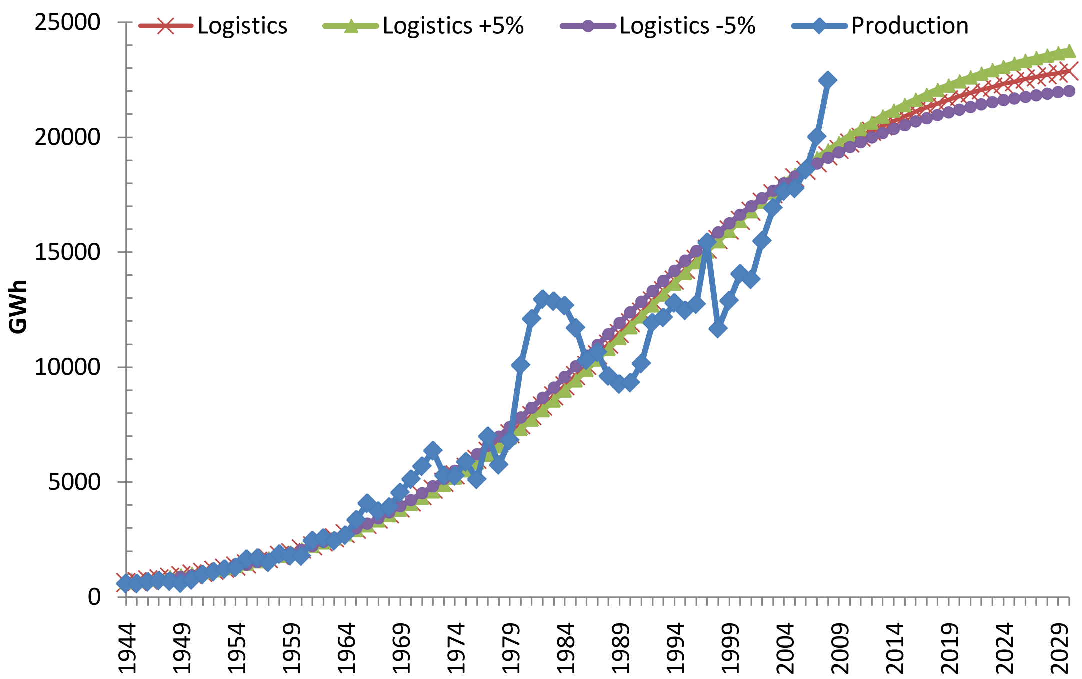


Figure 13 Electricity generation evolution from year 1944 to 2008 and logistic curve to 2030.

Figure 13 also shows the different events explained in Section 5.2. Also weather conditions are shown, for example droughts in 1948-1950 and in 1995. Nevertheless, most of the fluctuations that are not due to increase or decrease of capacity are due to national strategies concerning coal (DGA, 2005a).

As for installed capacity curves (see 5.2), production curves are also affected by new technologies. However, as is had been explained before, CC has less effect in electricity production 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 producing). This represents “only” a 22% difference, compare to more than 50% difference in the installed capacity asymptote.

6 Current situation of the energy sector

In this chapter the current situation of the energy sector will be explained. Evolution from year 1992 is described, 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 was included as separate data, and renewable energy separated in different sources. 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 4.6, 4.7 and 4.8. Thus in this section the electrical sector is not analyzed in detail.

It is important to remember that during this period Spain has undergone an important economic growth. Population has also grown, specially from 2002 (IAEST, 2010b). Therefore energy consumption has increase in general terms.

The RES-diagram for year 2008 (see Figure 14) is also included in this section. Although only year 2008 is represented, the RES-diagram can be used as a guide to understand the energy system in Aragón. The units used are toe. The RES-diagram represents each fuel with a line in a different colour.

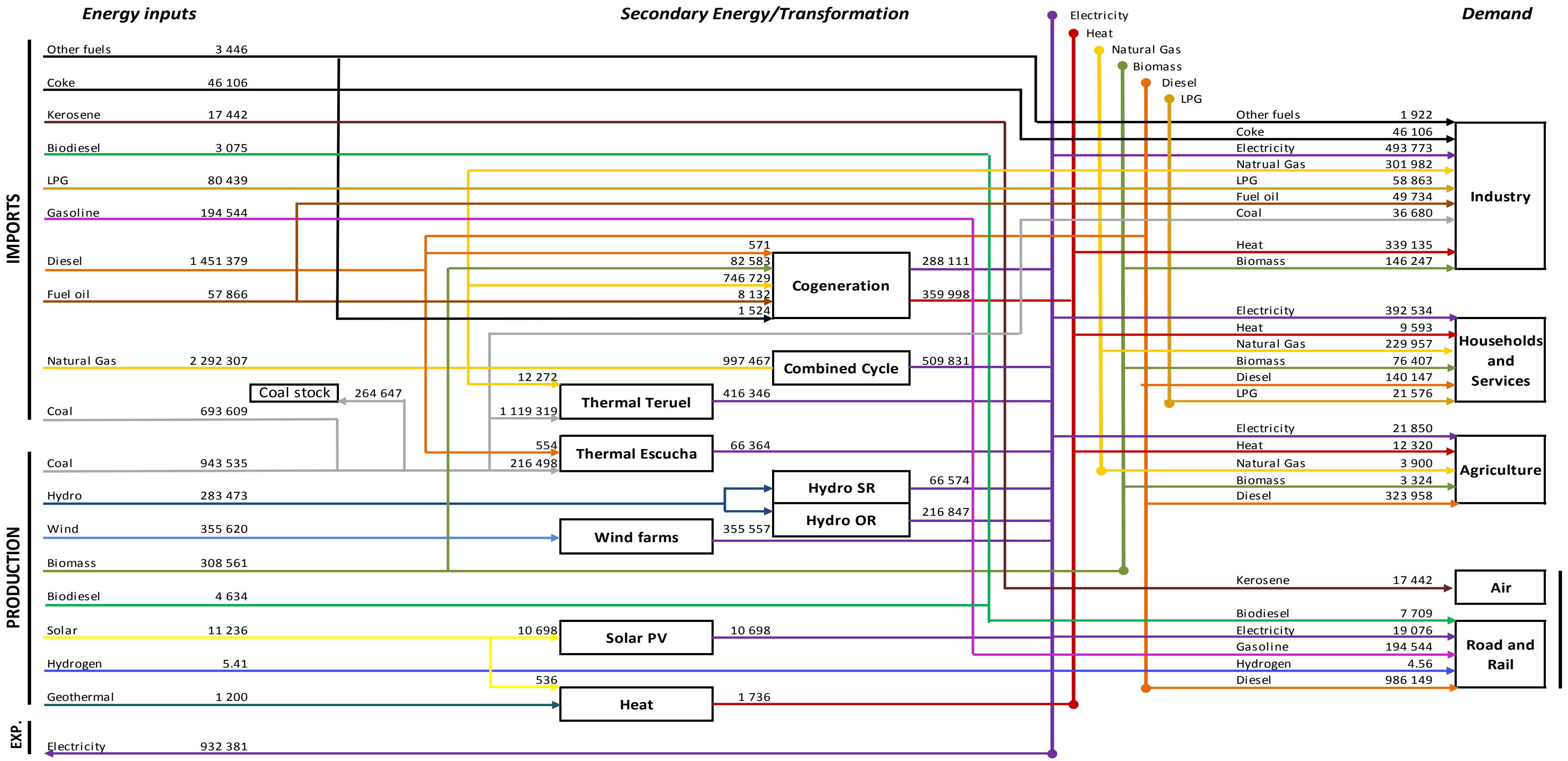
Starting from the left in the RES-diagram, there is a column with data about the energy inputs and the exports. The central column of the RES-diagram represents de transformation of the energy inputs into secondary energy, which in this case is electricity and heat. After this column, there is a vertical line for each fuel. It represents distribution and transportation losses. Finally, the last column includes data about final energy consumption, classified by sectors.

6.1 Evolution of the energy sector in Aragón from 1992 to 2008

6.1.1 Energy inputs

Using the RES-diagram in Figure 14 as a guide, the following explanation will start with energy inputs. Imports include all oil products, biodiesel, natural gas, coal (anthracite) and other fuels, which include used oils and waste. Production includes coal (lignite), biodiesel, hydro, wind, biomass, solar, hydrogen and geothermal. Finally, the only exports are electricity.

Evolution of total energy inputs consumption, exports, production and electricity exports are represented in Figure 15. Consumption and imports of energy inputs grow 2 371 ktoe and 2385 ktoe respectively. This represents 58% more consumption and 90.7% more imports in 2008 than in 1992. Electricity exports have undergone a 95% increase during these years. 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. The three most important sources of energy inputs are imported oil products, imported natural gas and coal, which is partially imported (see Figure 16).



Energy inputs	
Production	1 908 264
Imports	4 840 213
Total Bruto	6 748 477
Stocks	264 647
Total net	6 483 830

Transformation	
In	3 837 176
Out	2 292 061
Electricity	1 930 327
Heat	361 734

Own consumption	
Electricity	53 220
Heat	686

Distribution losses 2%

Final consumtion	3 934 933
Electricity	927 233
Heat	361 048
Natural gas	535 839
Biomass	225 978
Oil products	1 838 520
Other	46 315

Figure 14 RES-diagram for Aragón, year 2008. Units: toe. Source: (DGA, 2009a, DGA, 2009b, DGA, 2009c)

Figure 16 shows the energy inputs consumption in Aragón by sources from 1992 to 2008. 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. Thus natural gas was introduced first in cogeneration, and later in CC, for electricity generation (see Section 4.8). It has also substituted other fuels especially in the Industrial sector (DGA, 2005a).

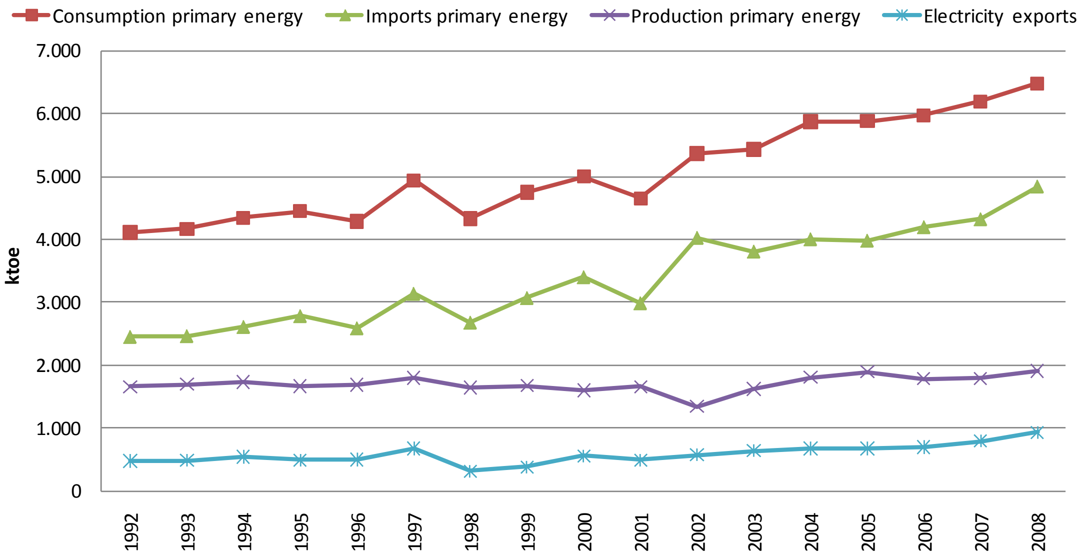


Figure 15 Evolution of the consumption of energy inputs, imports, production and exports of electricity from 1992 to 2008 in Aragón. Source: *(DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)*

During this period the used of oil products has increased in 559 ktoe. The use of oil products is important in Aragón because of high traffic density due to its location. Besides Aragón has always been a passing through area, and now this character has been increased since the region is focussing in logistics. Therefore the oil products use has increased. However, this increase is not as remarkable as the growth in natural gas.

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. Analysing Figure 5 and Figure 16 together the relation between the consumption of primary coal and the generation of electricity in coal thermal plants is clear.

The rest of the energy inputs sources have not undergone any important change, apart from wind. This changed is already explained in Section 4.

Figure 17 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 (Parliament, 2001).

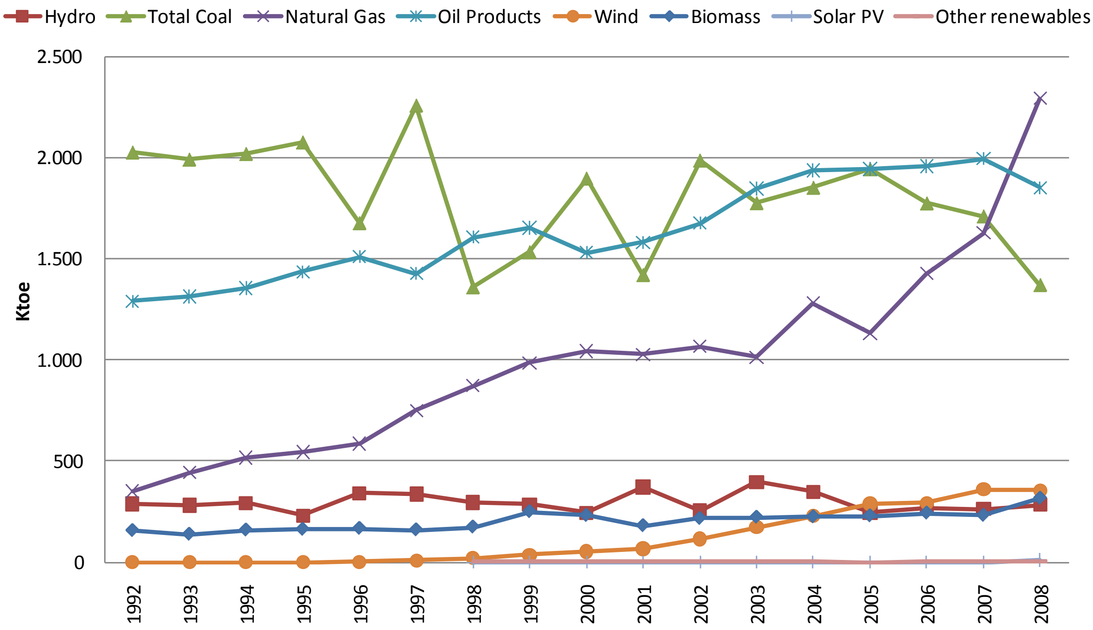


Figure 16 Energy inputs consumption from 1992 to 2008. Source:(DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)

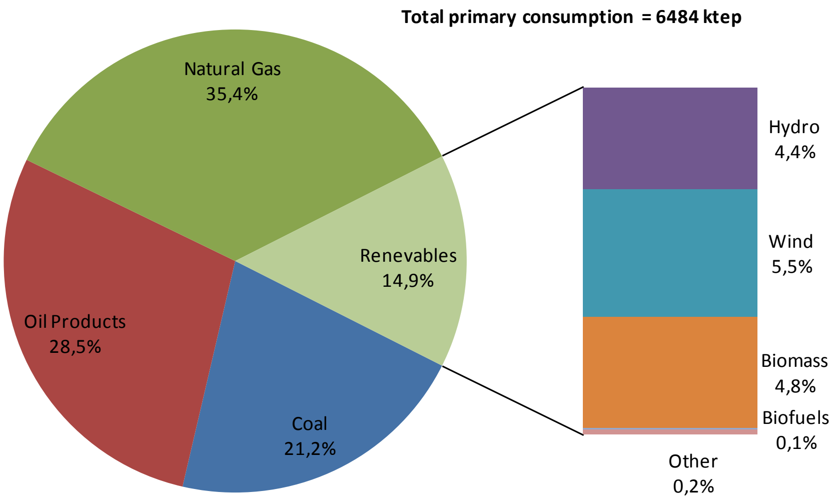


Figure 17. Energy inputs consumption by sources in Aragón in 2008. Source (DGA, 2009a, DGA, 2009b, DGA, 2009c)

6.1.2 Transformation

Following the RES-diagram (Figure 14), the next step is transformation of energy. As explained in Section 1.1, only electricity and heat generation are considered in this study. Electricity generation evolution is analysed in the previous sections. Therefore here only heat generation is explained. In the RES-diagram it can be observed how heat is only produced in cogeneration plants, with solar thermal and with geothermal. Cogeneration plants evolution has been explained with electricity generation in Section 4.8 . It is important to realize that heat is mainly used by the industry sector, since there is no district heating network in Spain. The presence of geothermal and solar thermal is insignificant, with less than 0.5% each. Geothermal energy produces every year a constant value of 1 200 toe. Each cogeneration plant will deliver 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 GLP boilers. That heat is useful energy, therefore the fuel used to obtain the heat is included in the RES-diagram, but not the heat itself.

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

6.1.3 Final energy

The right part of the RES-diagram represents final energy consumption. There is an overall increase of demand due to economic growth, from 2 211 toe in 1992 to 3 989 toe in 2008. Figure 18 shows the evolution of the fuels final demand in Aragón from 1992 to 2008, and Figure 19 the situation in 2008. Oil products are the most common fuels used during all the period. Although consumption of oil products increases steadily, their share in the total final consumption decreases from 60% in 2 992 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 used has been possible due to infrastructure development.

Heat demand also increases, in this case due to increase of cogeneration. Actually, heat demand has undergone 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. This is correlated with the explanation for cogeneration plants given in section 4.

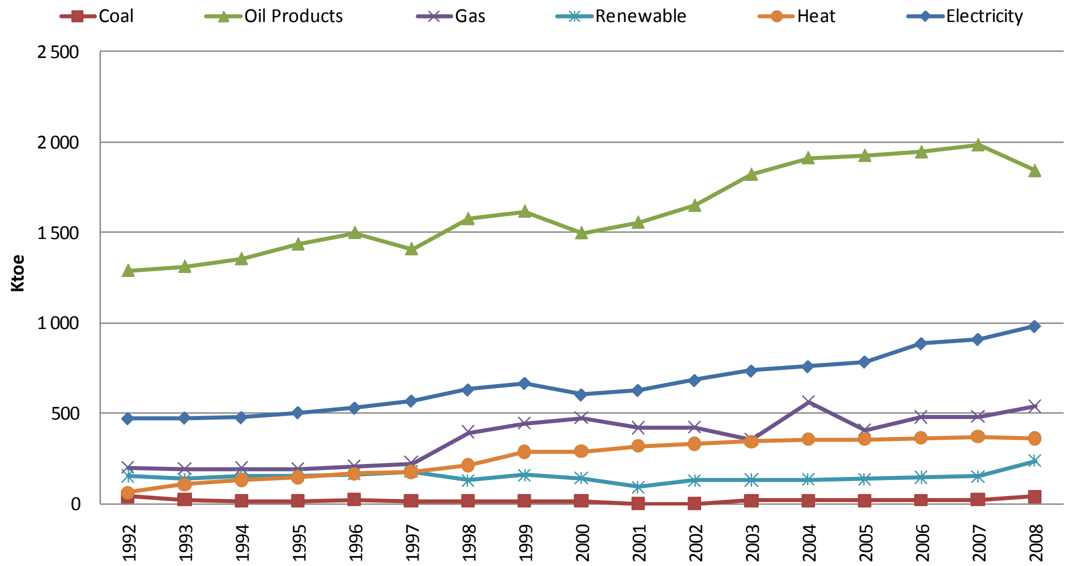


Figure 18. *Final energy consumption by sources from 1992 to 2008.* Source: own elaboration from (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)

Regarding coal and renewable sources, they remained approximately 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%.

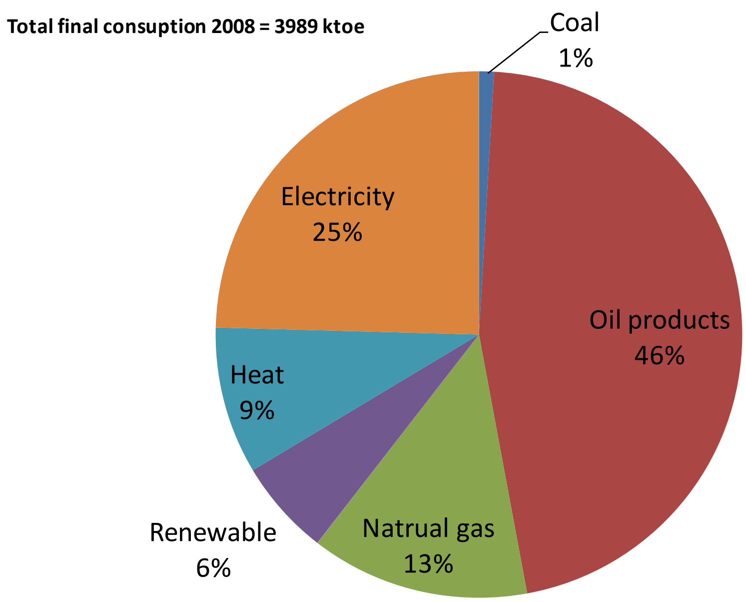


Figure 19 *Final energy consumption in Aragón in 2008. Source:* (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)

The share of the different sectors in the final energy consumption remains approximately constant, see Figure 20. Industry and transport are the sectors that consume more energy, both of them similar amounts, slightly above 30% during all the period. 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. Household and services sector remains approximately constant with a final period of increase. In total, energy demand in the Residential, Service and Commerce sector (RSC sector) has been multiplied by 1.4. While in 1992 RSC demand represented around 25%, in 2008 it was 20%. Finally, agricultural sector has the mayor relative increase with 326%. 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.

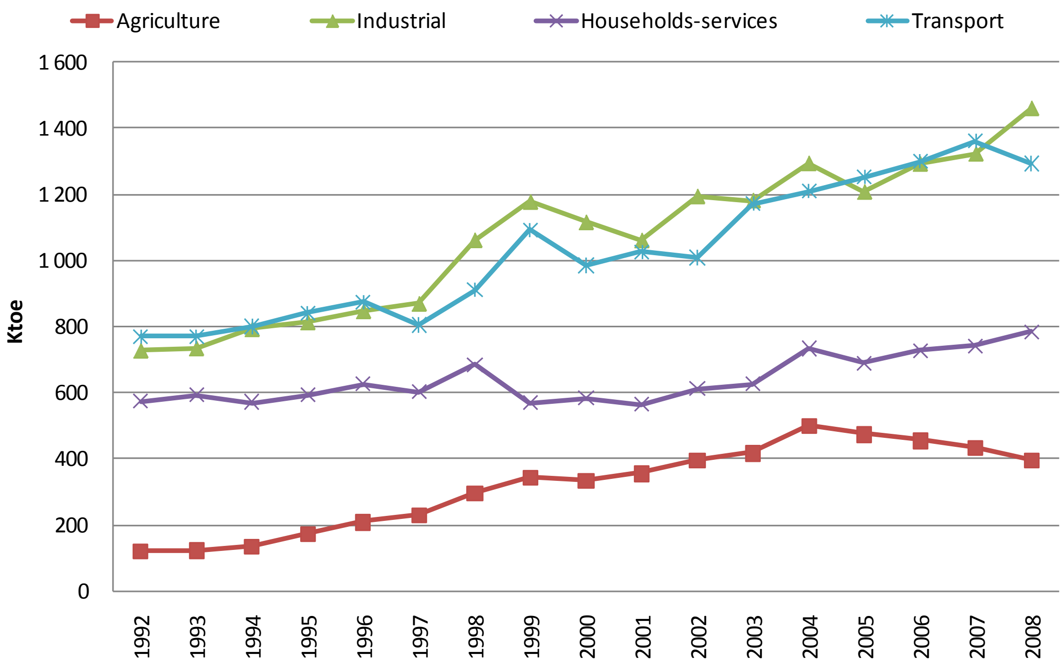


Figure 20 Final energy consumption by sectors from 1992 to 2008. Source: own elaboration from (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008)

In the following paragraphs each sector will be explained in more detail. The reason for this is that knowing the historical evolution of fuel use in each sector is necessary to understand the assumptions introduced in LEAP.

RCS sector use mainly electricity and natural gas. Natural gas is used for heating and cooking, while electricity is used for lighting and electrical appliances, and also for cooking. When there is no natural gas grid for heating, it is substituted by diesel, LPG, or heat pumps. A small amount of heat is consumed in big commercial centres with their own production plant, and in a smaller extent in houses with solar thermal installations. Heat from geothermal is used in a Spa. For cooling in summer, electricity is used

The RCS sector has undergone a mayor change during this period: substitution of oil products by natural gas from 1998 to 2000 (see Figure 21). Oil products changed from representing 65% of the final energy use in households in 1992 to represent only 10% in 2008. On the other hand, natural gas increased its share from 10% in 1991 to 30% in 2008.

Electricity has also increased its use and its share, substituting also oil products. While electricity represented 35% of the RCS demand in 1992, currently it represents 50%. Regarding renewable energy, it stays approximately constant during all the period, with an increase of only 14%. The less used fuel, heat, has increased more than 90 times from 1994 (first year that appears as fuel in RCS sector). However, it only represents 1% of the final energy consumption in the RCS sector.

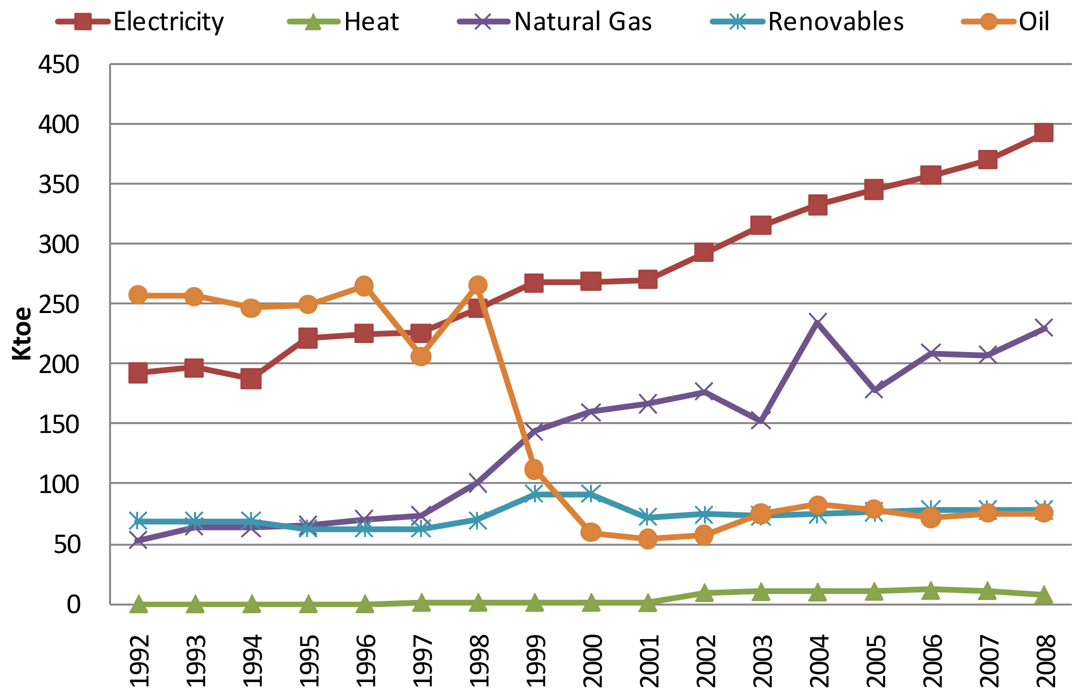


Figure 21 *Evolution of fuel consumption in the RCS sector in Aragón from 1992 to 2008.* *Source*: own elaboration from (DGA, 2000), (DGA, 2005a),(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008).

Electricity, natural gas and heat are the main secondary energy sources used in the industrial sector. Other minor fuels are used, changing every year their share since it mostly depends on the price relationship. Evolution of fuel consumption in represented in Figure 22.

Total consumption of electricity has increased 98%, however its share in the fuel mix is approximately constant around 35%. Natural gas has increased 107%, but its share remains at 21%, with maximums of 30% in 1998 and 2000.

Heat is the fuel that has spread more during these years in the industrial sector. From representing only 9% of the fuel consumption in 1992, in 2008 it represented 23%. However, the growth rate decreased from 2000, as the cogenerations facilities did not develop as in the 90´s.

The rests of the fuels remain approximately constant, with most of the fluctuations due to price changes. Coal share in the fuel mix changed from 4% in 1992 to 3% in 2008, since coal is only used in specific industries. Renewable energy (biomass) decreased from 12% to 10%, even with and important increase of 126% from 2007 to 2008. Oil products decreased their share from 20% to 10%, due fuel substitution.

Agricultural sector consumption is dominated by diesel. Electricity is mainly used for lighting and irrigation. Apart from the increase of consumption explained before, there have been small changes in the agricultural sector. Oil products represent at least 90% of the fuel share during all the period. Electricity has decreased it share from 10% to 5%. The substitute has been mostly heat, and biomass and natural gas in a smaller extent. This is because the mayor consumption is in transportation and machinery, therefore fuel substitution is not as easy as in other sectors.

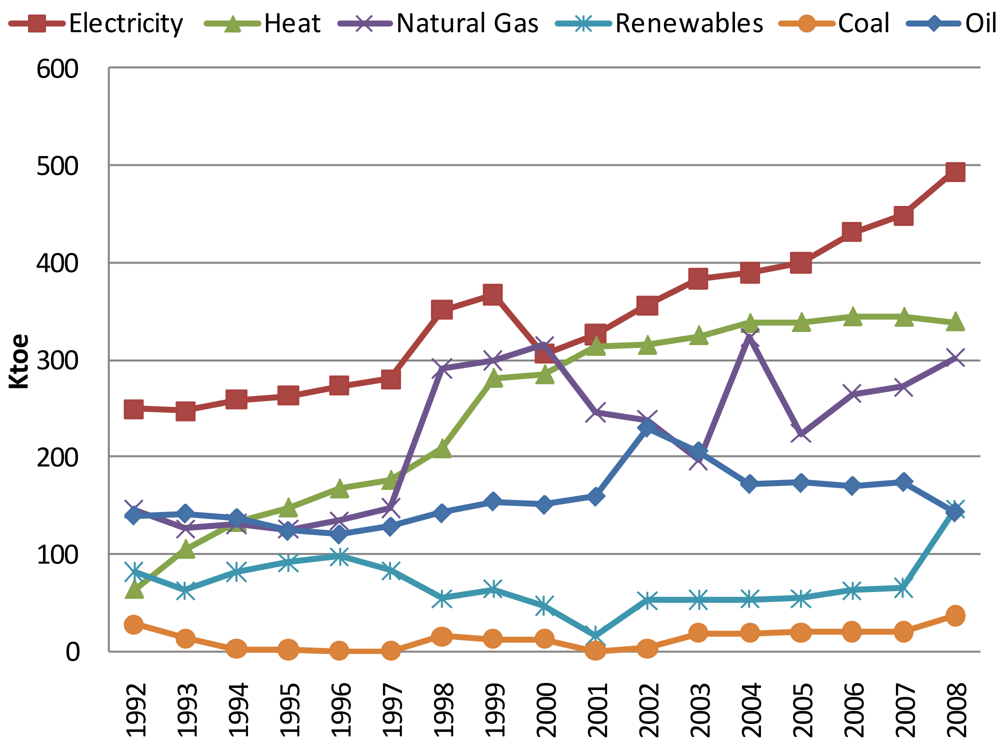


Figure 22 *Evolution of the fuel consumption in the Industrial sector in Aragón from 1992 to 2008. Source:* own elaboration from (DGA, 2000), (DGA, 2005a),*(DGA, 2007, DGA, 2009b, DGA, 2006, DGA, 2008).*

Finally, the transport sector consumes mainly diesel and gasoline. Gasoline is used only for road transportation, while diesel is also used to power trains. Electricity is used in trains, while kerosene is used in air transport. There is a small consumption of hydrogen that was used during year 2005 to power transportation during an international event in Zaragoza. Biofuel represents also a small amount of the fuel used.

There are no important changes in this sector, apart from the increase of consumption already explained. Electricity has increase 40% during the period, due to increase of use of electricity in trains. Biofuels only represent 0.1% of the total final energy consumption in the transportation sector, but since 2005 they have multiplied by 14.3.

For a better picture of year 2008, fuel share by sector is shown in Figure 23. For more detailed data about the entire energy sector see the RES-diagram in **¡Error! No se encuentra el origen de la referencia.**

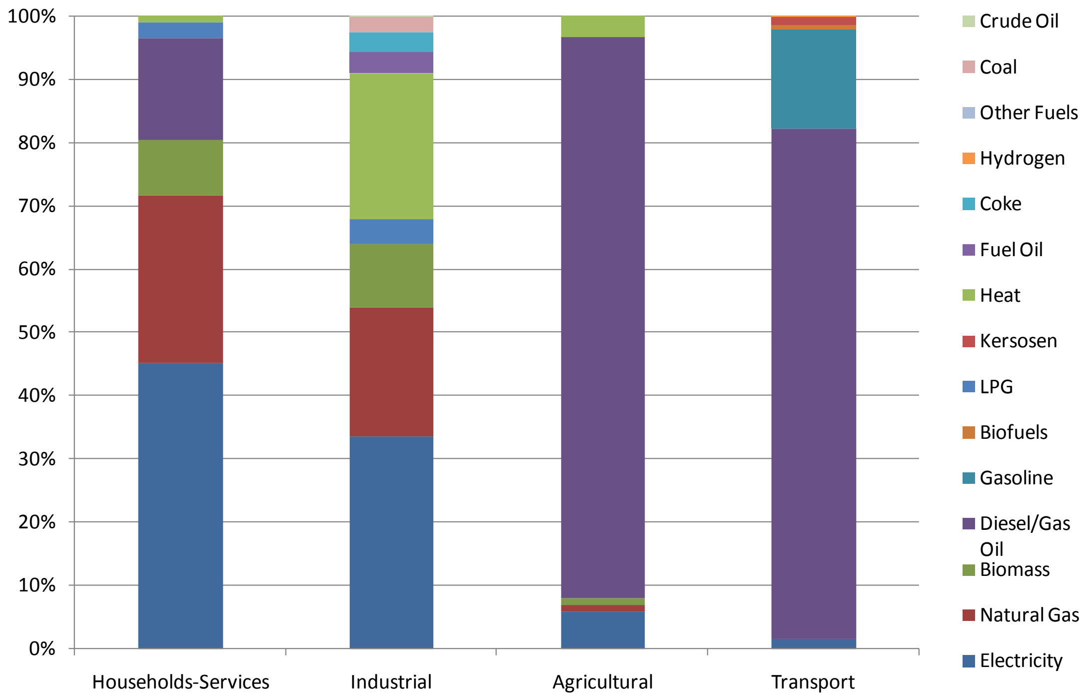


Figure 23. *Fuel consumption share by sector in 2008. Other fuels include waste and recycled oils. Source (DGA, 2009a, DGA, 2009b, DGA, 2009c)*

7 Scenarios

In this chapter an explanation of the different scenarios is provided. Main data and assumptions are explained for each scenario.

7.1 Base year

Year 2008 is the base year for calculations, which means that first year simulated is 2009. Data for year 2006 and 2007 are also introduced. For an explanation of the energy system in Aragón in 2008, see Section 6.1

Data regarding cost come from the Energy European Commission (European Commission, 2007). For electricity generation, cost estimates are provided for each fuel in € per MWh, and 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 take into account all lifecycle of the fuel.

Cogeneration is a special case since it uses different fuels. 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.

LEAP provides environmental data in a database called TED. Each fuel is liked with it emissions through this database. IPCC emission values are used it this study. Each fuel used to produce electricity or heat is linked with the environmental load in TED. Final energy sources are also linked to TED, but not electricity or heat. For these fuels LEAP calculate the emissions produced in the demand branch by using the data provided in the transformation branch. This procedure avoids double accounting.

A list with the data introduced in LEAP, source, units and comments is included in Table 6. In the key assumptions, the variable Air Traffic Units is included to measure the air transportation activity later in the demand branch. One traffic units is either one passenger or 100 kg of goods (Ministerio de Fomento, 2008). This unit was chosen since passenger and freight transport could not be distinguished due to data availability.

For each sector in the demand branch, activity level, final energy intensity, efficiency and fuel share had to be introduced in LEAP. Activity level is a measure of the activity in which energy is used. Population is chosen for RCS sector, VA for agriculture and industry, and air traffic units for air transport. For road and train transport it was not possible to find a unit suitable to data available, since road and rail transport must be measured. Therefore total consumption is considered. Final energy intensity is the energy consumed in the sector divided by the activity level. For example, in the RCS level it is final demand in RCS divided by population. Efficiency of the devices is not considered in this study, as explained in Section 1. Finally, fuel shares have been explained in Section 4.8.

In the transformation branch there are four variables that need to be explained. The first one is the reserve margin. Reserve margin is the surplus of installed capacity that LEAPS considers that is enough to cover peak demand. If this variable is set lower than the system needs, then LEAP will calculate how much of the energy demand is not met. In the base year it is calculated by LEAP.

The second variable is the exogenous capacity. Exogenous means that it is defined from outside LEAP, therefore in the base year exogenous capacity is equal to installed capacity. For future scenarios, exogenous capacity contains data about the future capacity that is confirmed. Thus, a new variable is needed, endogenous capacity. Endogenous capacity is the installed capacity that LEAP adds to the scenarios in order to cover the energy demand. This variable is defined in each scenario.

The third variable is maximum availability. Maximum availability is the percentage of hours of the year that a power plant can generate electricity. For the base year it is calculated by LEAP.

The last variable is 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. 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.

The last branch of the tree, resources, covers reserves and yield limits for this study. Coal lignite reserves are introduced. Regarding renewable energy, the maximum possible annual yields obtained by wind and solar in Aragón are introduced. Hydropower limit is not introduced because it is a mature technology and therefore is approximately in its limit. Geothermal is a special cases because there is no data about the possible maximum yield, and very little information about its use. Besides, since 1992, geothermal has produced the same amount of heat, 1200 toe. Therefore, and due to ignorance about this energy source, the limit is set to 1200 toe.

Table 6 Data used for base year.

	Source	Units	Comments
Key assumptions			
Demographic			
Population		people	
Households	IAEST	household	http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_06/IAEST_0601/IAEST_060101/IAEST_06010103
Household size	IAEST	people	http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_06/IAEST_0601/IAEST_060101/IAEST_06010103
Economy			
GDP Spain	INE	Euro	
Income	calculated as GDP/population	Euro	Usual practice when using LEAP
GDP	IAESTE	Euro	http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_00/IAEST_001DB/IAEST_001DB_INDICE/IAEST_001DB07
Value added	INE	Euro	http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft35%2Fp010&file=inebase&L=0
Fuel demand	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	toe	Coke, crude oil and other energy fuels have always the value from 2008, due to data available http://portal.aragon.es/portal/page/portal/ENERGIA/PUBLICACIONES/BOLETIN
Final Demand Sectors	Summ of fuels demands	toe	Oil products distribution between sectors does not match completely with the RES published by the DGA, even if their instructions are followed.
Transport			
Air traffic units	Environmental report from Zaragoza airport	Trafic units	1 pasanger = 1 traffic unit; 100 Kg = 1 traffic unit http://www.aena.es/csee/ccurl/3/51/ZAZ_Informe_Mediambiental_2008_ES.pdf
lectricity production share	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	% total electricity	
Demand			
Household and Services			
Activity level	Data population	people	
Final energy intensity	Calculated as final demand sectors/population	toe/person	
Efficiency		%	100%, useful energy is not included
Fuel share	Calculated as fuel final demand/ final demand sectors	%	
Agriculture			
Activity level	Data value Added agriculture	Euro	
Final energy intensity	Calculated as final demand sectors/value added	toe/€	
Efficiency		%	100%, useful energy is not included
Fuel share	Calculated as fuel final demand/ final demand sectors	%	
Industry			Same procedure as in Agriculture. Fuel oil is considered as Diesel in LEAP
Transport			
Air transport			Data available did not allowed to distinguis between passenger and freight transport
Activity level	Data Air traffic units	Traffic units	
Final energy intensity	Calculated as kerosene demand/Air traffic units	Toe/Traffic units	
Efficiency	none	%	Considered 100%, not included in this study
Fuel share	Bulletin 21 and 21, Department of Industry, Commerce and Turism. DGA	%	Kerosene is considered the only fuel in airport and to be used only for air transport
Road and Train transport			Diesel is used by both road and train transport, and data with separate uses is not available. Electricity is only used in trains
Activity level		No data	Total consumption is considered
Final energy intensity	Final demand	toe	
Fuel share	Calculated as final demand/final demans sectors	%	
Transformation			
Distribution losses			Only considered for electriciity according to data availability
Electricity	Excel document provides by DGA, Energy Balances 92-97	%	Same value every year, 2%
Own consumption			Only considered for electricity. Heat own consumption included in heat generation
Electricity	Calculated from bulletin 22,20, 18. Department of Industry, Comerce and Tourism	%	Data from 2008, 5%

	Source	Units	Comments
Heat generation			
Output fuels			
Heat properties	Energy balances 92.97 and 98-2007		Electricity considered a co-product. Heat is the priority product, cannot be imported or exported. Surplus is wasted.
Processes			
Process share	Bulletins 17, 18, 19, 20, 21,22. Department of Industry, Commerce and Turism	%	
Process Efficiency	Bulletins 17, 18, 19, 20, 21,22. Department of Industry, Commerce and Turism	%	Considered 100% for solar thermal and geothermal. For cogeneration is calculated as heat out/energy in.
Coproduct Efficiency	Bulletins 17, 18, 19, 20, 21,22. Department of Industry, Commerce and Turism	%	Calculated as electricity out/energy in. 0% for solar thermal and geothermal.
Cogeneration			
Auxiliary fuels	Bulletins 17, 18, 19, 20, 21,22. Department of Industry, Commerce and Turism	%	Heat consumed by energy sector. Introduced as heat consumed per toe of heat produced.It is set so heat consumed comes from cogeneration.
Feedstock Fuels share	Bulletins 17, 18, 19, 20, 21,22. Department of Industry, Commerce and Turism	%	Fuel oil is considered as Diesel in Leap
Electricity generation			
Load curve	Bulletins 21, 22. Department of Industry, Commerce and Turism		Load curve for year 2008
Reserve margin	calculated by LEAP		
Output fuels			
Electricity			Posible to export.Surplus is exported. Priority to exports.
Electricity exports	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	toe	
Processes			
Dispatch rule			In ascending merit order. First renewables, second CC, third coal thermal.
Process share	Data electricity production share	%	Process share does not summ 100% since part of the electricity production occurs in heat generation
Process efficiency	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	%	Considered 100% from hydro, wind power and solar PV. Coal thermal and CC calculated as energy out/energy in.
Historical production	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	MWh	
Exogenous capacity	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	MW	Production capacity
Maximum Availability	calculated by LEAP	%	
Capactiy credit	Calculated as Maximum Availability/Maximum availability Coal Thermal	%	Method suggested by LEAP as an aproximation
Coal thermal			
Feedstock Fuels share	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	%	Fuel oil is considered as Diesel in Leap
Resources			
Primary			Land use is not included in this study.
Coal Lignite reserves	Aragonese Enciclopedia	tonne	Study from year 1992
Renewables max. yield	Renowables 2050	TWh	Hydro power limit not considered
Geothermal max. yiel	Bulletins 17,18,19,20,21,22, Department of Industry, Commerce and Turism	toe	Fixed production of geothermal in all bulletins
Costs			
Electricity generation cost	Average EU energy policy data	€/MWh	Cost from 2005. 10% discount rate and 1€=1.25$. 3% Inflation in LEAP.
Heating cost	Average EU energy policy data	€/toe	Lifecycle cost
Cogeneration	Average EU energy policy data	€/toe	Biomass considered woodchips. Total price calculated as price woodchips*share of biomass+price of fossil fuels*share of fossil fuels.
Emissions			
All emisions	LEAP, IPCC Tier 1 report		

7.2 Business as usual (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 3.1), available information and historical trends (see Sections .4, 5 and 6).

7.2.1 Key assumptions

Demographical data forecasted are: population and number of households. Population forecast is available from the National Statistics Institute (INE, 2010) until year 2019. After that LEAP extrapolates the results with a linear forecast. This method was chosen because it fits better with data provided by INE than other methods available in LEAP. Percentage growth of number of households is available in DG TREN. Average yearly growth for Spain is considered a good approximation for Aragón. Figure 24 shows historical population and forecast to 2030.

Economical data forecasts are extracted from the reports *Europe's Share of the Climate Change* and DG TREN. Both reports contain forecasts for Spain that are introduced in LEAP, and LEAP calculates forecast for Aragón starting with historical data and applying the same growth as forecasts for Spain has. When annual change is available, this value is introduced directly in LEAP.

GDP is a very important assumption in LEAP, since different variables are set to grow as it does. Figure 25 shows historical GDP data for Spain and Aragón, as well as future values calculated by LEAP. It is clear the historical correlation between Spanish GPD and Aragonese GDP, and the calculated values follow the same trend. Figure 26 illustrate the Value Added (VA) for the different sectors in the economy in Aragón.

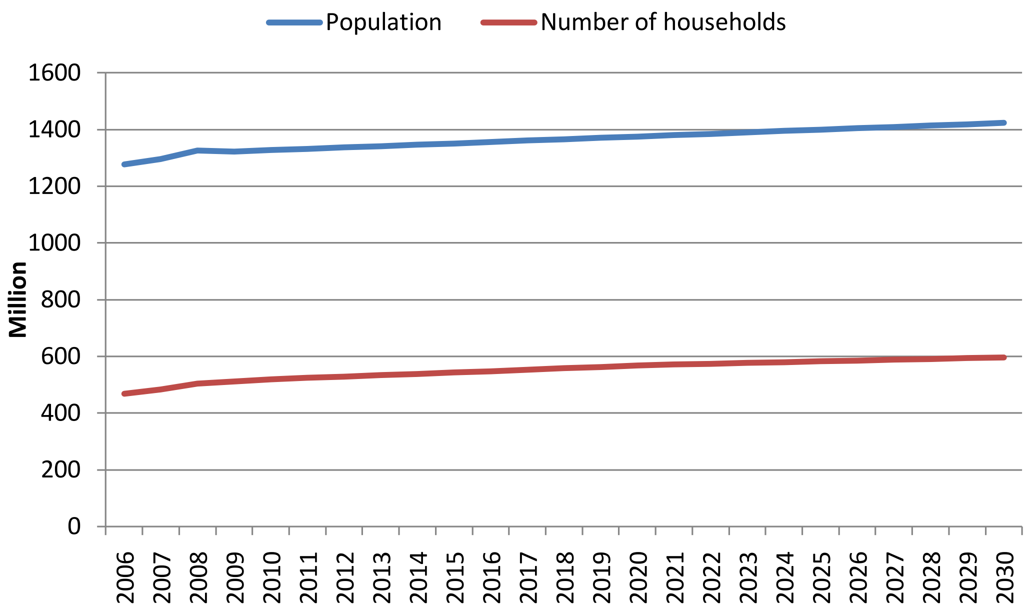


Figure 24 Population and household forecasts for Aragón. Sources for population forecast: (IAEST, 2010b, INE, 2010), LEAP calculation from 2020 to 2030. Sources for number of households forecast: (Prof. P. Capros, 2008)

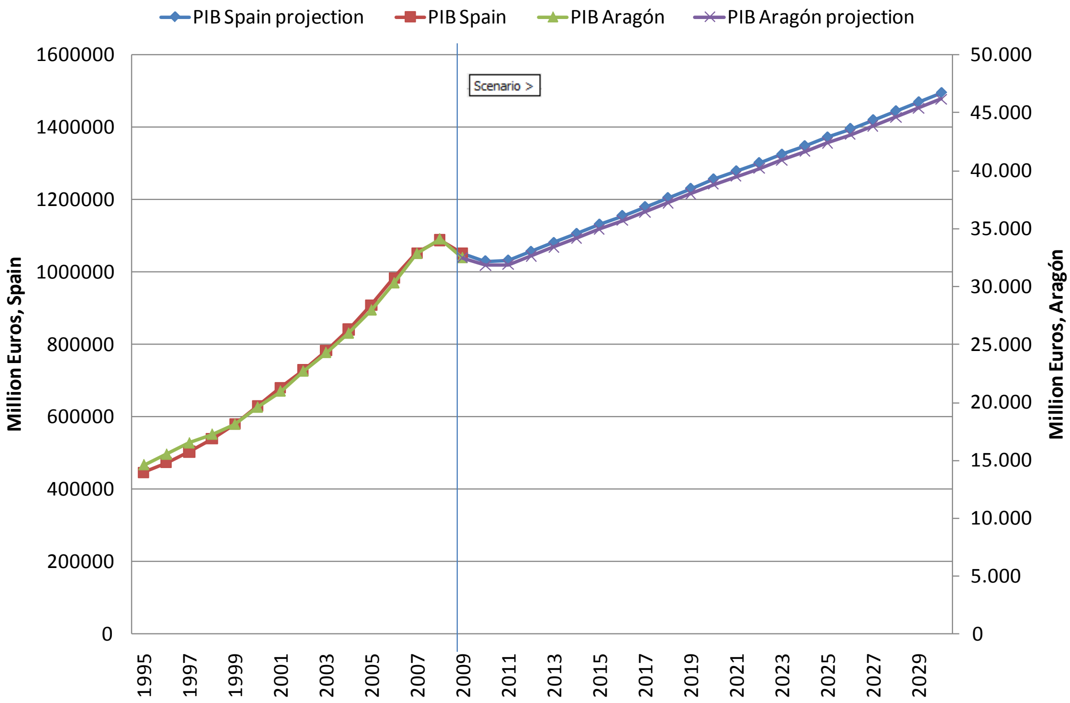


Figure 25 *GDP forecast for Aragón. Source: (IAEST, 2009), calculated in LEAP using forecast for Spain from (Heaps et al., 2009).*

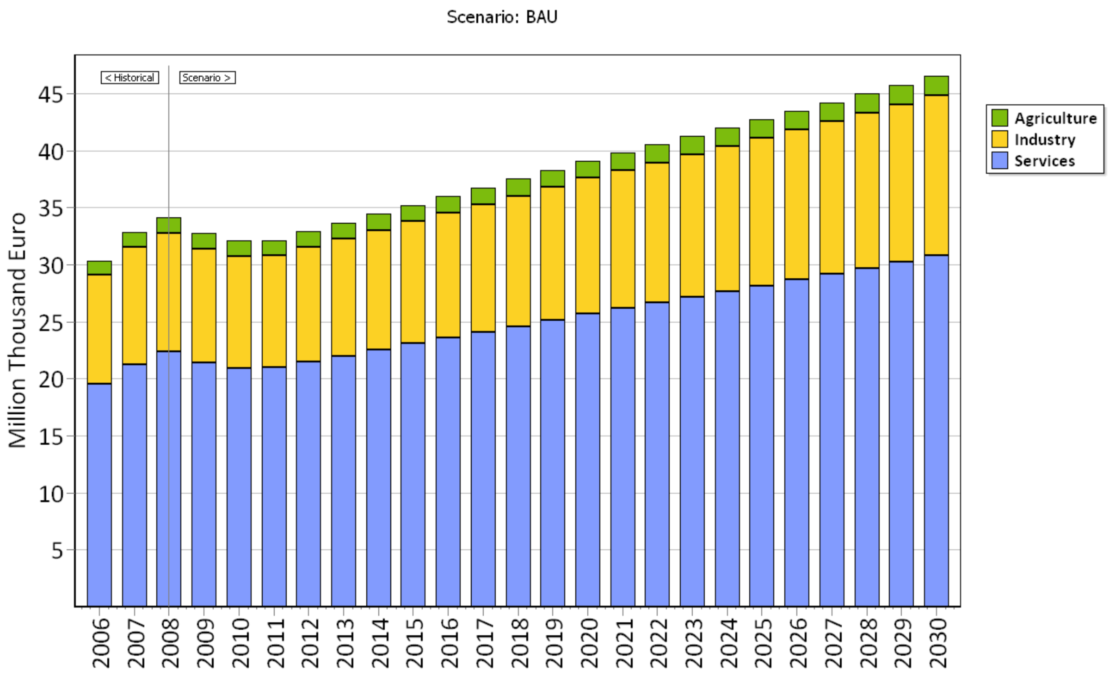


Figure 26 *Value added forecast for Aragón. Source:(INE, 2010), calculated in LEAP from forecasts for Spain in (Prof. P. Capros, 2008).*

Cost forecasts are available from the Energy European Commission (European Commission, 2007), with the same procedure as for the base year. The European Commission introduced a CO_2 price from 20 to 30 €/tone CO_2.

Emission factors remain as in the base year.

Fuel demands are included in key assumptions to make easier the definition of the historical data. For the scenario definition the demand changes are included in the demand branch, with hydrogen and kerosene as exceptions. Hydrogen is not considered to grow in the BAU scenario. Kerosene annual percentage increase from DG TREN is used for this fuel.

Regarding sector's final demand, transport demand is the only fixed in the key assumptions branch. Air transport final demand is the same as the demand for kerosene. Road and train transport yearly percentage increases is taken from Spanish data in DG TREN.

Traffic units are set to grow as Spanish traffic units in the report Europe's Share of the Climate Change. Forecast for the airport in Zaragoza is not available, therefore using Spanish average seem like a good approximation.

Finally, Spanish electricity demand is added as a new variable in the key assumptions branch. Spanish electricity demand is used by LEAP to forecast electricity exports from Aragón. Data is available from the INE web page and forecast in DG TREN.

7.2.2 Demand

Demand forecasts are different for each sector. Taking into account past trends and forecasts fuel share for each sector was decided for 2030. For years in between 2008 and 2030, a linear interpolation is made by LEAP. Values for 2008 and 2030 are presented in Table 7. For an explanation of the past trends see Section 6.1.3.

The RCS sector final energy intensity is set to grow as the income from Aragón. Forecasts indicate that fuels shares are not expected to have very important changes, although a growth of electricity and natural gas is expected together with a decrease in the use of oil products. Biomass will continue its slow decrease. Heat demand will continue increasing, mostly due to solar thermal (Prof. P. Capros et al., 2008, Charles Heaps et al., 2009). See Table 7 for detailed fuels shares in 2030.

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. This decision is made following both historical trends and forecasts.

Final intensity of the industrial sector 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, heat will substitute 2% of natural gas use by 2030. Biomass share remains with the same value than in 2008, which is considered a high value since it is double the share than the previous years. The rest of the fuel's shares in the final industry will remain constant. Table 7shows values for 2030.

Regarding air transport, activity level grows according to *Europe's Share of Climate Change,* and Kerosene demand grows as demand for aviation in Spain in DG TREN. Road and Train transport final energy intensity (in this case total consumption) follows the forecast given by DG TREN for transport, without including air transport and navigation consumption. Electricity demand for transport grows as demand for electricity in transport in DG TREN. Biofuel consumption grows linearly to a value of 9.2% in 2030, which is the value suggested in *Europe's Share of Climate Change.* 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.

Table 7 Fuel share in the different sectors in the BAU scenario.

	2008	2030
Households		
Electricity	45.11%	50%
Natural Gas	26.43%	30%
Biomass	8.75%	8%
Heat	1.10%	2%
LPG	2.48%	1.5%
Diesel	16.10%	8.5%
Agriculture		
All fuels	No changes	
Industry		
Natural Gas	20.48%	18.48%
Heat	23.00%	25%
Other fuels	No changes	
Road and Rail Transport		
Electricity	1.58%	1.1%
Diesel	81.67%	77.1%
Gasoline	16.11%	12.6%
Biodiesel	0.64%	9.2%

7.2.3 Energy transformation I. Losses, own consumption and heat generation

Percentage of transportation losses and energy sector own use of electricity will remain constant in the BAU scenario.

Heat generation module is set to cover all heat demand (no capacity limit) for two reasons. The first one is the data availability regarding capacities to introduce in LEAP. The second one, and more important is the structure of the energy system regarding heat. In this system, the demand for fuel "heat" is only created if the heat plant is available. Otherwise, the final utility "heat" will be covered with other fuels, such as natural gas or electricity. For example, a factory will only have heat demand if it has a cogeneration facility. Otherwise the heat needed will be provided by other fuels. A house will only demand heat when it has solar collectors. Otherwise the demanded fuel will be, for example, natural gas. In other words, an increase of heat demand always means that the heat capacity has been increased.

Therefore there are only three possible parameters to change in the heat generation module: 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 changes are:

- Geothermal production limit is 1200, from historical data. Therefore geothermal share decreases slightly from 0.33% to 0.28%
- Solar thermal percentage of participation will grow as demand for heat in houses grows. This means that it changes from 0.15% in 2008 to 0.31% in 2030.

- Cogeneration will still cover almost 100% of the heat demand in 2030.

7.2.4 Energy transformation II. Electricity generation

To explain the changes introduced in the electricity mix for the BAU scenario, each technology and important parameters are going to be explained in detail bellow. Different data considered will be explained, as well as the final data included in LEAP.

In general, no important power plants are planned for a short term period, as can be seen in Figure 28. In this map with the most important power plants in Aragón in 2010, no new plants are expected (REE, 2010).

Load curve and merit order

Figure 27 represents the electrical system load curve for year 2008, which is used for all scenarios.

Merit order is determined at country level. First are nuclear and renewables, cogeneration, hydro power, and finally coal and CC. Therefore, merit order is decided as follows (1 represents base load):

- Renewables, including all types of hydro power: merit order 1
- CC merit order 2.
- Coal merit order 3. This value is set to represent so the program calculates the decrease of coal that had happened from 2008.

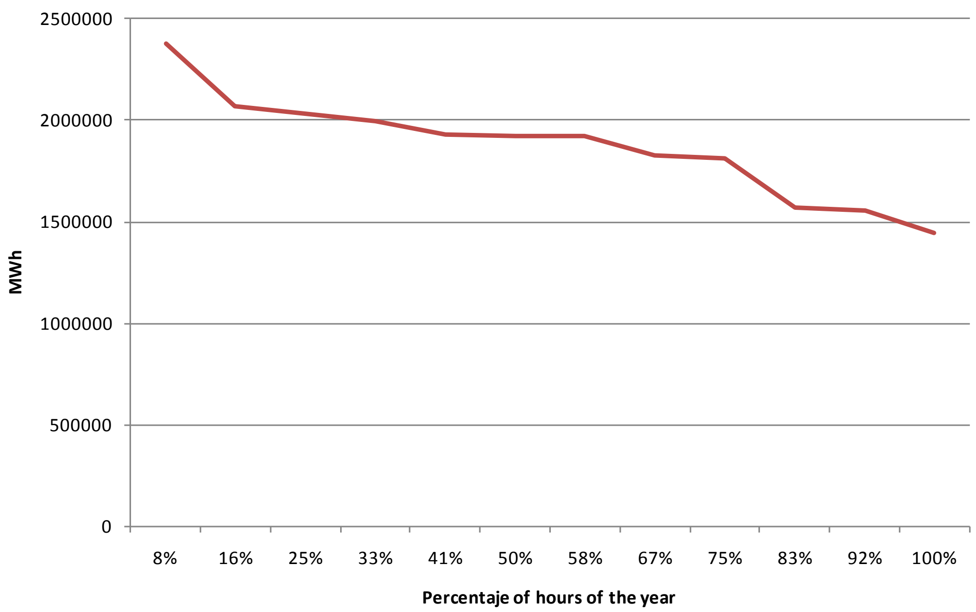


Figure 27 Load curve for year 2008. Source: own elaboration from (DGA, 2009c, DGA, 2009b)

Reserve margin, maximum availability and capacity credit

Reserve margin is set to 30% until 2019 and 45% from that year. Iteration has been necessary until the correct values have been found and demand of electricity was met.

Maximum availability has been set to the maximum historical value, for all of the technologies but CC. Historical availability of CC is not representative of the reality. Therefore 65% was chosen, since it is the value used for Spain in the report *Europe's share of the Climate Change (Charles Heaps et al., 2009).*

Capacity credit is calculated by LEAP as in the base year.

Figure 28. *Electricity grid and power plants in Aragón in 2010. There are no new power plants planed. Source: REE (REE, 2010).*

Coal thermal

The most important change in electricity mix is that coal thermal is expected to lose its important presence. UNESA's forecast predicts that Escatrón closes during 2010, although it did not produce electricity since 2008 (DGA, 2009b). Escucha closure is calculated for 2010. Finally, Teruel power plant is expected to close between 2019 and 2020. However, The Energy Plan for Aragón does not include the closure of Escucha before2012. On the other hand, since 2008 the production of electricity from coal power plants has suffered a very drastic decrease. In May 2010 coal power plants in Aragón are to a high extent stopped (Public Library of Andorra, 2010). The electricity mix proposed by the Spanish government for 2020 expects a decrease of 3 770 MW in installed capacity in Spain, while the actual installed capacity in Aragón is 1 341 MW.

Taking all this information into account, for this study the following capacity decreases will be included:

- Escatrón will close in 2010
- Escucha will close in 2012
- Teruel will close two of the modules in 2019 and the last one in 2020.

Since coal is a strategic resource for Aragón and Spain, it is expected that new coal thermal power plants will be built. However, there is social opposition to traditional thermal power plants (S. Campo, 2009), so it is difficult that a new big coal power plant is built once Teruel power plant is close. Currently there are only two coal power plants in very early stages of planning:

- Mequinenza, 37 MW (DGA, 2010).
- Ariño, 49.9 MW

Therefore it is decided that LEAP can introduce endogenously 40 MW thermal power plants when new capacity is needed.

Hydro power

None of the considered reports forecasts and important growth in hydropower capacity. Only the government proposal includes an important increase in pumped-storage hydro, which according to this proposal will double by 2020.

The CNE report includes an addition of 400 MW in an existing power plant in Moralets in 2013. This is the only increase included in the BAU scenario.

Combined cycle

Combined cycle power plants are in a very uncertain situation. In 2005 there were four projects for new CC power plants in Aragón, with a total of 3 085 MW (DGA, 2005b):

- Castelnou, 800 MW. Currently working.
- Osera de Ebro, 800 MW
- Escatrón, 800 MW. Currently working
- Sástago, 400 MW
- Escatrón-Peaker, 285 MW. Currently working as a simple cycle.

Since 2005 another project has been added, a 800 MW plant in Fayón (B.O.A, 2007). However, projects seem to be stagnated due to the economical situation and a decrease in the demand. As shown in Figure 28, REE does not considered them yet and the report of the CNE considers only some of them, and as very uncertain. Besides, the forecasted capacity of 2000 MW in the Energy Plan for 2012 is almost achieved in 2008. Therefore, for this BAU scenario no additional capacity will be added. UNESA gives 30 years life time for combined cycle plants, so existing plants will remain in 2030 and no decrease in capacity is considered either.

Nevertheless, CC power plants can be introduced in the system by LEAP if they are needed. Although the most common capacity seems to be 800 MW, LEAP can introduce 400 MW CC power plants. This allows more flexibility and resembles to a certain extent the construction of a bigger power plant in smaller steps.

Wind power

Historical trend for wind power in Aragón shows stagnation of the installed capacity around 1700 MW since 2007. Yearly increases have changed from 100% and 60 % in 2001 and 2002, respectively, to 12% and 1% in 2007 and 2008. The reason for this is that Aragón is one of the regions in Spain with more wind power capacity installed, and one of the first that started. Therefore past increases in capacity installed are not expected in the BAU scenario. In other words, in the BAU scenario wind power is considered to be a mature technology in Aragón.

Taking into account this information, increase in wind power capacity in Spain can be expected to occur mainly in other regions, not in Aragón. Anyway, three forecasts for Spain are considered:

- DG TREN forecasts for Spain a 7.5% yearly growth in installed capacity until 2020 and 1.3 % after that, when the market is considered mature.
- The Spanish government proposes an increase of 16700 MW of installed capacity in Spain until 2020, reaching a similar result to DG TREN's forecast.
- However, UNESA forecasts a 9000 MW increase until 2020.

The DGA forecasted in 2005 that in 2012 there will be 4000 MW of wind power installed in the region. As in 2008 the installed capacity was 1 715 MW and the preliminary data for 2009 is 2009, the goal of 4000 MW seems very difficult to reach in the short term.

Considering all this information, for this BAU scenario a 1.3% yearly increase in wind power is introduced in LEAP. Figure 29 shows the historical trend with the DGA planned capacity for 2012, the forecast that results from applying the yearly increases form DG TREN and the forecast used in this study. If an increase similar to UNESA's forecast was applied, the result would be in between these two forecasts.

This is a conservative forecast, and it is considered in this scenario intending to represent the maturity of the market for wind power in Aragón. Therefore 1.3% is chosen because it is the increase considered in DG TREN for the Spanish mature market. Despite this, it is important to notice that this does not mean that in the BAU scenario wind power has achieve its maximum capacity in Aragón. Much more area could be use to build wind farms, and existing wind farms could be repowered. But these changes are not considered in this BAU scenario.

LEAP can also introduce 100 MW of wind power if more capacity is needed. Summing up, LEAP can introduce 3 types of plants endogenously: 100MW wind power, 400 MW CC and 40 MW coal, in that order.

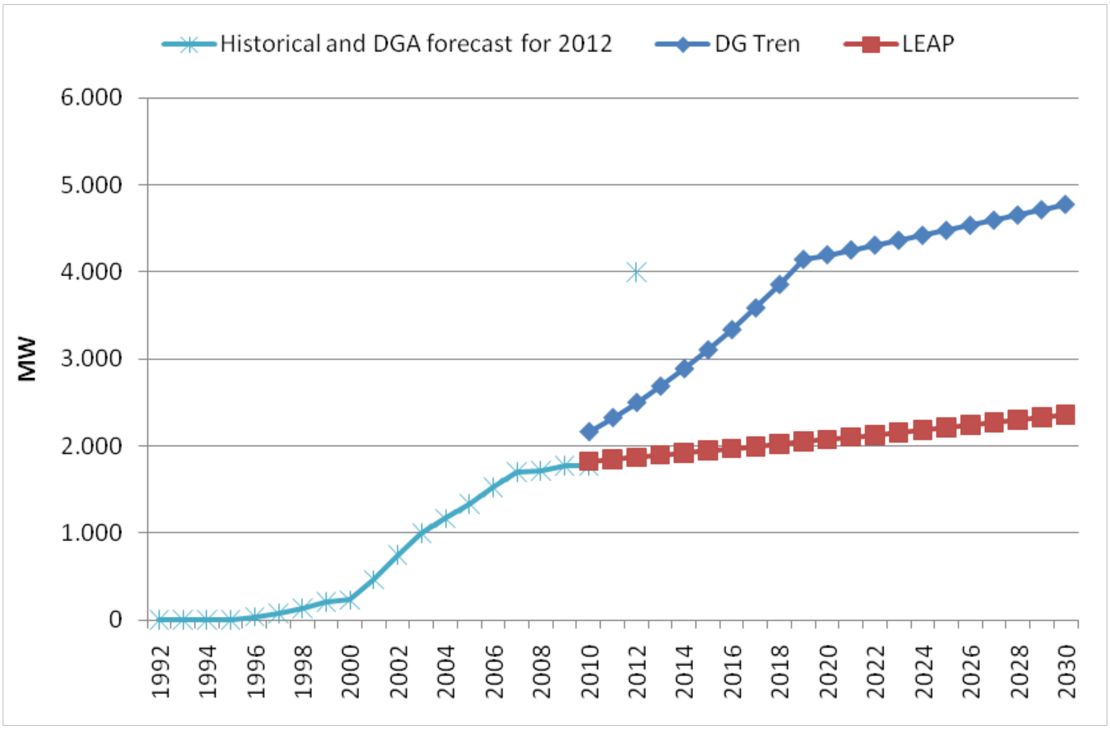


Figure 29 Historical data and forecasts for wind power.

Solar power

As explained in section 4.7, solar energy is currently in a very uncertain situation. The reports considered where all made before the spectacular growth of solar energy in Spain during 2008. The only exception to this is the proposal of the Spanish government. The government propose an increase of 11 520 MW in solar power by 2020. This includes both solar thermal and solar PV. On the other hand, past growth rates are not expected to continue. It is important to notice that there is a lack of forecast and studies regarding solar energy, especially considering solar PV and solar thermal separately.

Currently most of the solar PV projects have installed capacities around 2 or 3 MW. There are no solar thermal plants in Aragón, although there are several projects in early planning stages, accounting for 564 MW in 2009 (IDAE, 2009). Some of them are:

- Berlver de Cinca, 3 groups with a total of 115 MW (B.O.A, 2009a)
- Los Llanos, Huesca 50 MW (IDAE, 2009)
- Perdiguera, Zaragoza, 50 MW (IDAE, 2009)
- Bovedal, Zaragoza, 50 MW (IDAE, 2009)
- Las Hoyas, 50 MW Teruel (IDAE, 2009)
- Castelnou, Teruel 50 MW (IDAE, 2009)
- Ibersol Teruel, 50 MW (B.O.A, 2009b)

There is no planned date to start operation in any of these plants, but t is sure none of them is going to start operation before 2011. Therefore, it is considered for the BAU scenario that growth until 2020 will resemble the proposal of the government. This gives 500 MW to Aragón in 2020. With no better available forecast, after 2020 solar power increases 7.7% every year (value from DG TREN).

Figure 30 shows the different forecasts for solar power. It can be observed that DGA and DG TREN forecast are similar if 2008 is not considered in the calculations. However, when applying the yearly percentage growth including 2008, DG TREN forecast is very optimistic. Thus, the forecasts used in this BAU scenario can be considered in between.

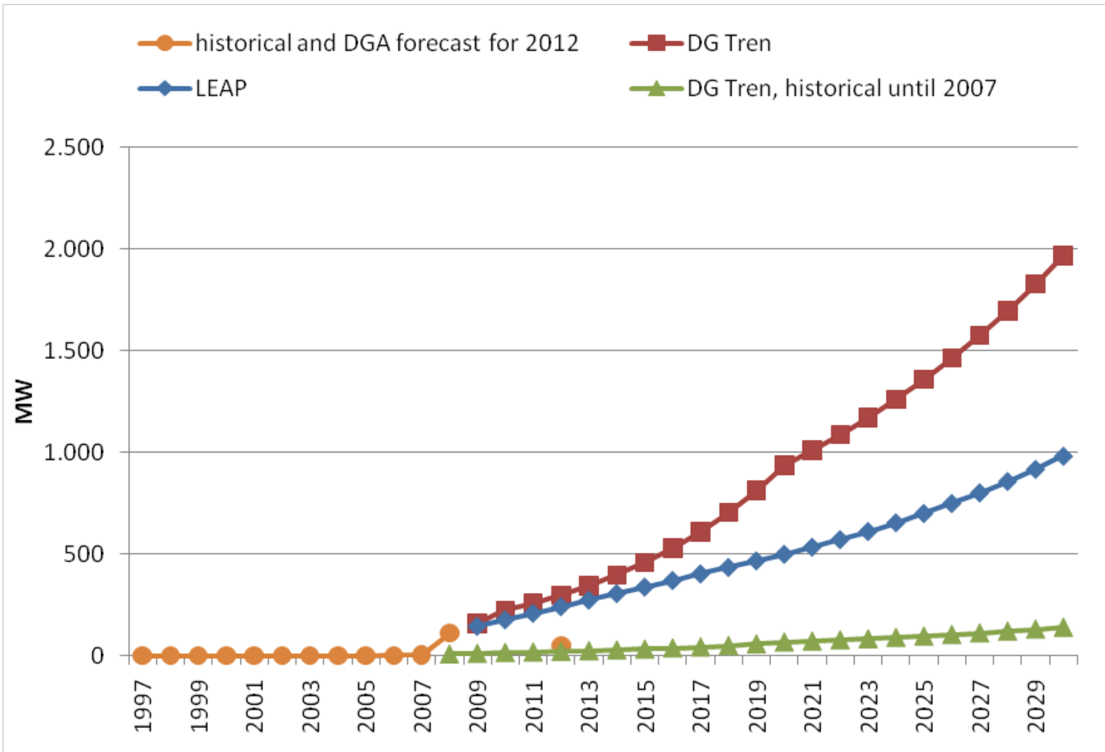


Figure 30 Historical data and forecast for solar power, both PV and thermal.

7.3 Coal priority scenario (COAL)

The COAL scenario aims to represent a situation where the coal thermal power plants are given an advantage position in the electrical system in Spain. As explained in this report, coal is a strategic resource for Aragón and Spain, but during the last years electricity generation from coal thermal power plants has decreased drastically. To avoid different problems in the short and medium term, the government aims to produce 15% with Spanish coal from 2011 (B.O.E, 2010).

Nevertheless, this scenario does not aim to represent the introduction of the new legislation, since a more deep study is needed to study it. COAL scenario tries to answer the question "What if coal power plants become base load?" So the only parameter that changes is the merit order of the coal thermal power plants. From being in a third place in the BAU scenario, in the COAL scenario their merit order is one from year 2011. Also the order of the endogenous addition of installed capacity gives priority to coal, changing from the third position to the second.

7.4 Renewable electricity (REN)

In the REN scenario the main assumption is that the only possible power plants to be built use solar or wind energy. No technological changes are introduced, which underestimate the effects of this situation. The more the renewable technologies are introduced in the system, the better their performance and cost.

The change introduced in this scenario is the types of power plants that LEAP can introduce in the system. In the REN scenario it can introduce 100 MW of wind power and 100 MW of solar power. Exogenous Coal thermal and CC capacity installed in maintained as in BAU scenario, since it only includes decrease of coal thermal and already existing CC power plants. The difference with the BAU scenario is that in the REN scenario LEAP cannot introduce new plants that use fossil fuels.

7.5 Electric cars scenario (ELECAR)

This scenario assumes that the current programs to support electric cars achieve their aims. Existing programs end in 2014, and after that the main assumption is that the electric car demand continues growing. In 2030 every car registered will be electric. Notice that this scenario cannot be considered as a detailed study of the transportation sector. 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?"

The most important assumption is the number of electric cars to be considered. In Spain 250 000 car are expected to be registered from 2011 to 2014. One of the objectives of the plan is that the cars are spread over the country, in each city with more than 50 000 inhabitants (Ministery of Economy and Treasury, 2010b). In Aragón, only Huesca and Zaragoza fulfil this requisite. After analysing the relationship between the demand of cars in Spain and in Huesca and Zaragoza from 1999 to 2008, it can be said that every year approximately 2% of the new cars in Spain are purchased in this region. Values for the cities could not be found; therefore this value will be used. This leads to an optimistic result, but as explained before a more detailed study in needed regarding the transportation sector. Besides, current objectives of the policies are very optimistic, as well as the assumption of immediate success that has been made as a key point for this scenario.

Thus, 2% of the new electric cars in Spain will be registered in Aragón. This makes 400 cars in 2011, 1000 in 2012, 1400 in 2013 and 2200 in 2014. LEAP calculates a logistic forecast for the number of electric cars registered each year, with previous data as input. The asymptote of the logistic curve is required by LEAP. The asymptote is calculated as the average number of cars registered since 1999, which is 30000 cars. Figure 31 shows historical data as well as the results of the calculations in LEAP. It also shows a linear extrapolation of the total number of cars. Using that extrapolation, in 2030 46% of the cars in Huesca and Zaragoza would be electric cars. Life span of a electric car is considered to be from 18000 days (49 years) to 20000 days (IDAE, 2010). Therefore, the new electric cars are considered to be in use until 2030.

All the changes introduced in the REN scenario are also valid there. This is decided because one of the aims of the electric car is to increase the presence of renewable energy in the system (REVE, 2009).

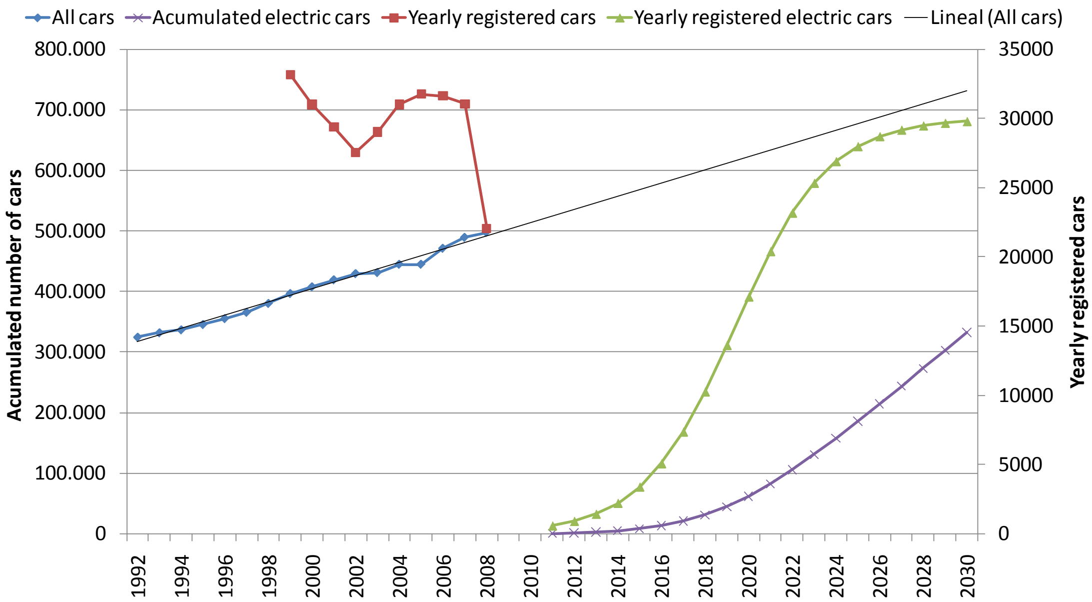


Figure 31. Number of cars in Huesca and Zaragoza from 1992 to 2008, registered cars in Huesca and Zaragoza from 1999 to 2008 and calculations in LEAP for electric cars from 2009 to 2030. Source: (IAEST, 2010a) and own calculations.

The second important assumption is the electricity consumption of each car. Considering a yearly consumption of 15000 km/car and 14 kWh/km, an average electric car would consume 2.1 MWh/year (REVE, 2009). Regarding traditional cars, the average consumption is set to 7 litres per 100 km. Each kilometre travelled with an electric car substitutes a kilometre travelled with a traditional car.

Cost of the policy is 590 millions of Euros from 2010 to 2012 (Ministery of Economy and Treasury, 2010b). The cost for Aragón would be 2% of this value, the same proportion as the electric cars introduced in Aragón. The program continues until 2014, but data about the cost expected after 2012 could not be found. Thus, costs are estimated to be constant at 3.9 million Euros from 2010 to 2014. This value is calculated as the 2% of 590 million Euros divided by 3 years (2010, 2011, and 2012).

8 Scenario results

In this section the results from the calculation in LEAP are explained. First the BAU scenario is explained and then each scenario is compared with it.

8.1 BAU

Energy inputs consumption increases to 6 947 ktoe in 2030 after reaching a minimum of 6 037 ktoe in 2009 (see Figure 32). 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.

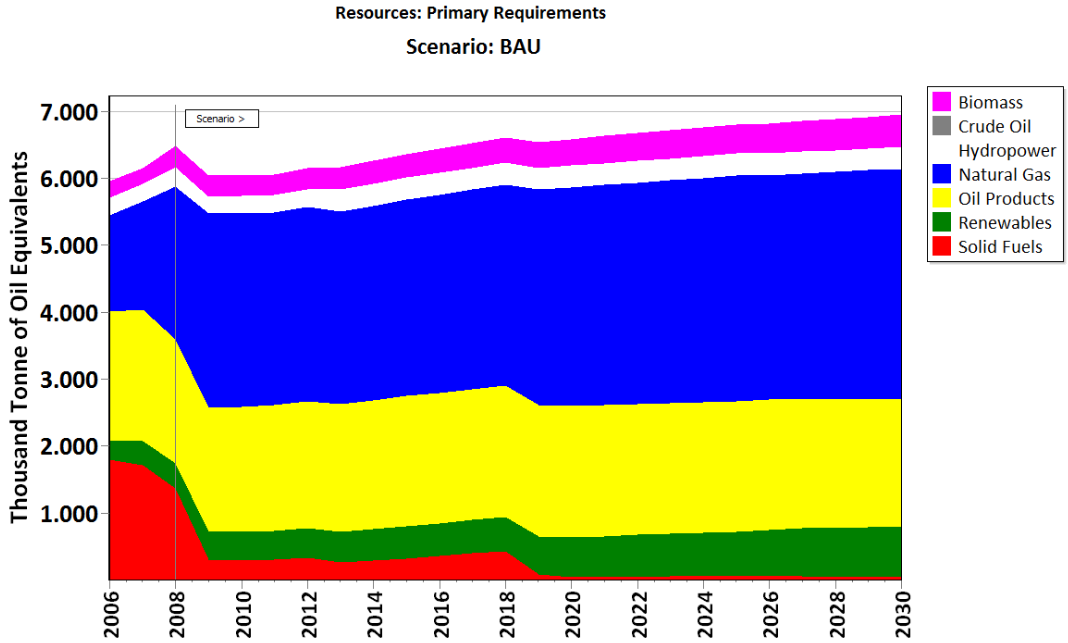


Figure 32. Energy inputs requirements for the BAU scenario. Biomass includes biomass and biofuels, solid fuels includes all types of coal, renewable includes wind, solar, geothermal and hydrogen.

Fuel share in 2030 is represented in Figure 33, which can be compared with fuel share in 2008 (Figure 17 in page 43). 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.

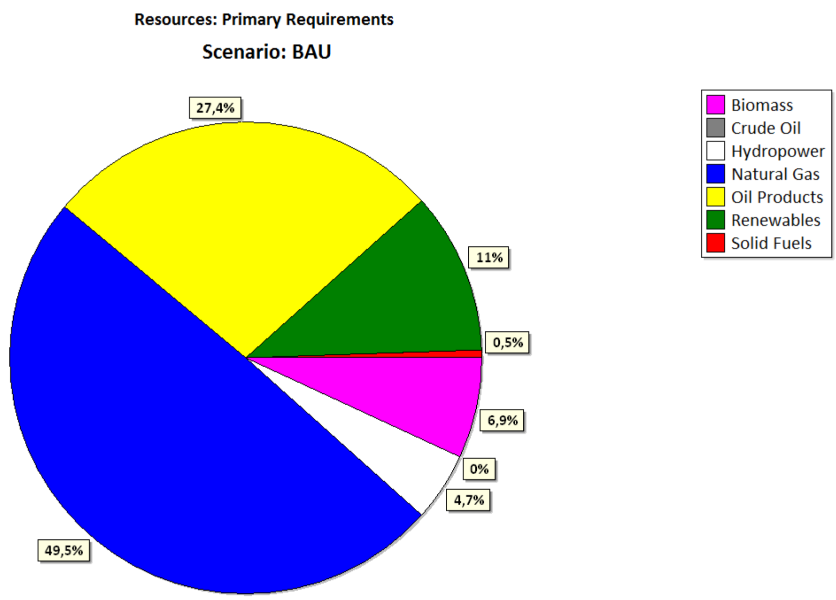


Figure 33. *Energy inputs consumption in 2030. BAU scenario Total energy consumption is 6806 ktoe.*

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. Besides the changes explained in Section 7.2.4, 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. In 2019 the new installed capacity is 1080 MW: 200 MW of wind power, 800 MW of CC and 80 MW of coal thermal. During 2020 half of the capacity is installed: 100 MW of wind power, 400 MW of CC and 40 MW of coal thermal. Finally, in 2014 it introduces a coal power plant, in 2016 a wind power plant and in 2028 a CC power plant.

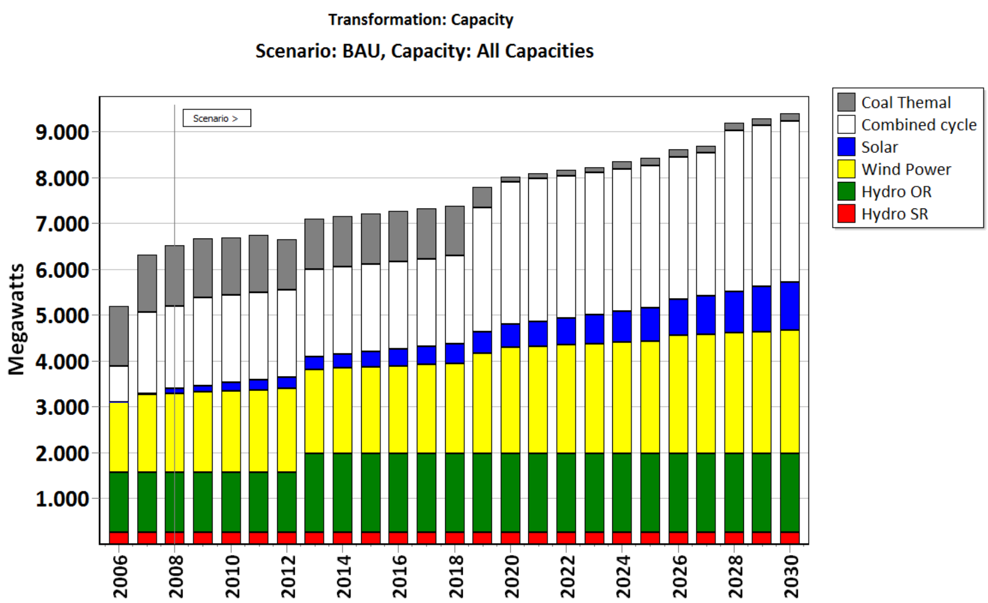


Figure 34. *Installed capacity without cogeneration. BAU scenario*

The power dispatched also changes during the years. The first important change can already we observed in year 2009, one year after the base year (see Figure 36 and Figure 27 for comparison). While until 2008 coal thermal generated electricity all year long, in 2009 it is only used as peak load during half of the year. At the end of the simulation period the change is more important: even if there is 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, which is the reason to have coal thermal even if in a normal year coal thermal power plant is not needed.

The most important change in electricity generation is, again, the decrease of coal thermal to zero production. Electricity generated without including cogeneration increases to 24 181 GWh in 2030, a 27% more than in 2008. Figure 35 shows the evolution of the electricity generated by the different technologies. As explained, coal thermal contribution decreases from 30% in 2008 to 5.8% in 2015 and finally 0% in 2030. Combined cycle is the technology that has the highest growth, from representing 31% of the electricity generation without including cogeneration in 2008 to represent 47.5%. Solar power multiplied its production by 13.6 during this period. Since the production in 2008 is small, in 2030 solar power produces “only” 1 792 GWh, which represents 7.4% of the electricity production without considering cogeneration. Regarding wind power, it production grows 72% to 7 103 GWh in 2030. It represents 30% of the electricity produced without considering cogeneration. Finally, hydro power grows only 16% until 2030.

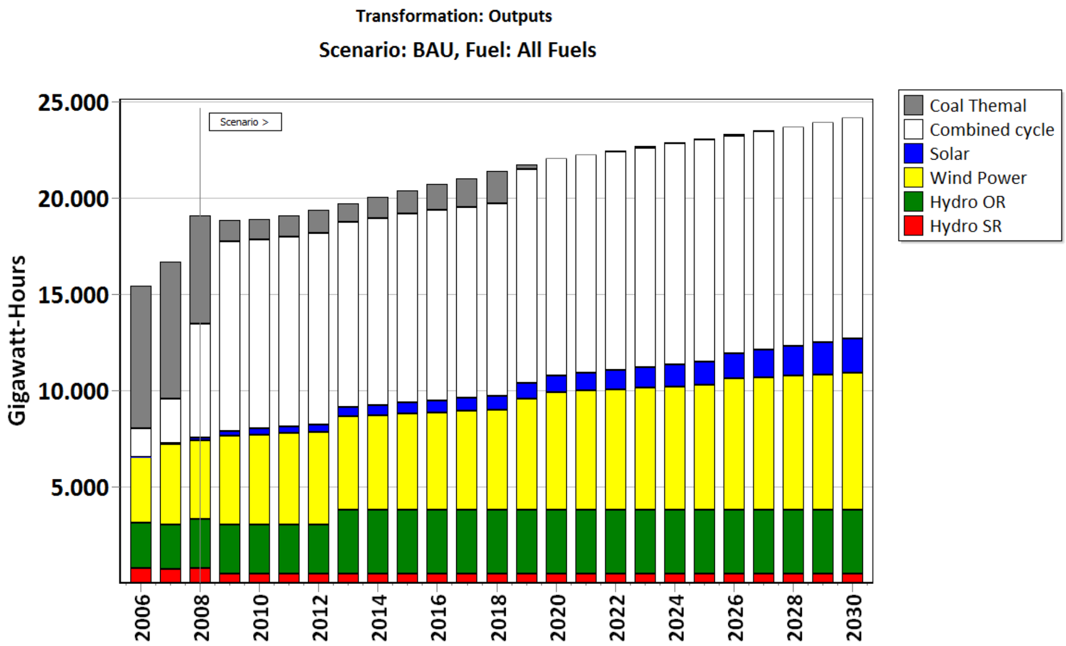
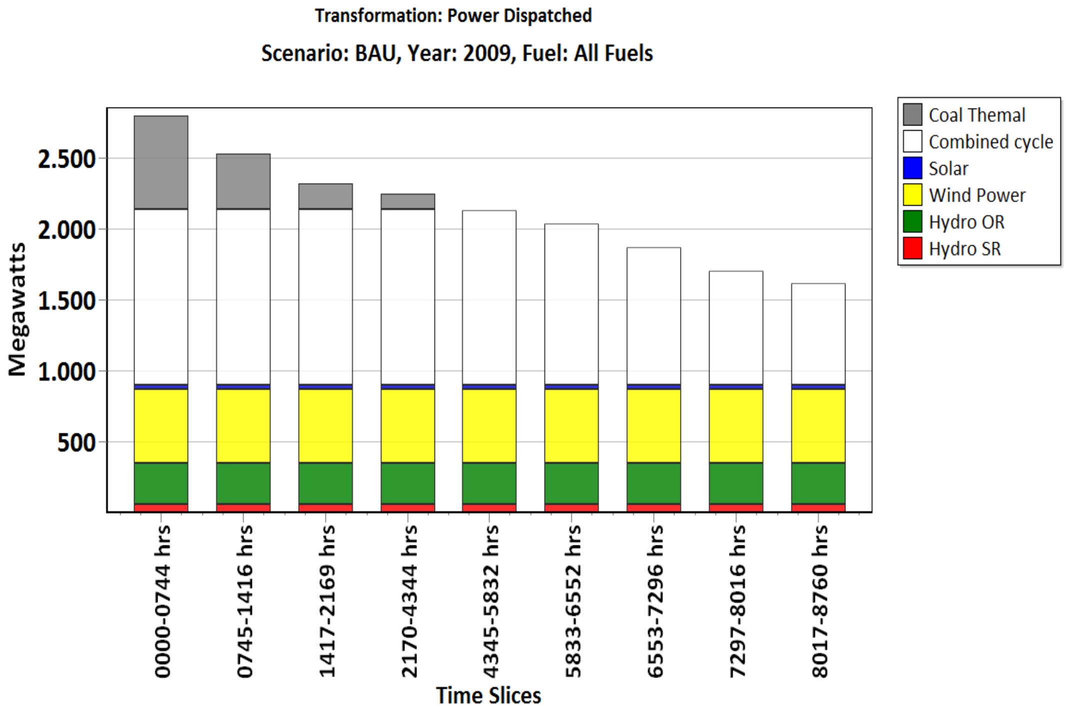


Figure 35 Electricity generation without cogeneration. BAU scenario.



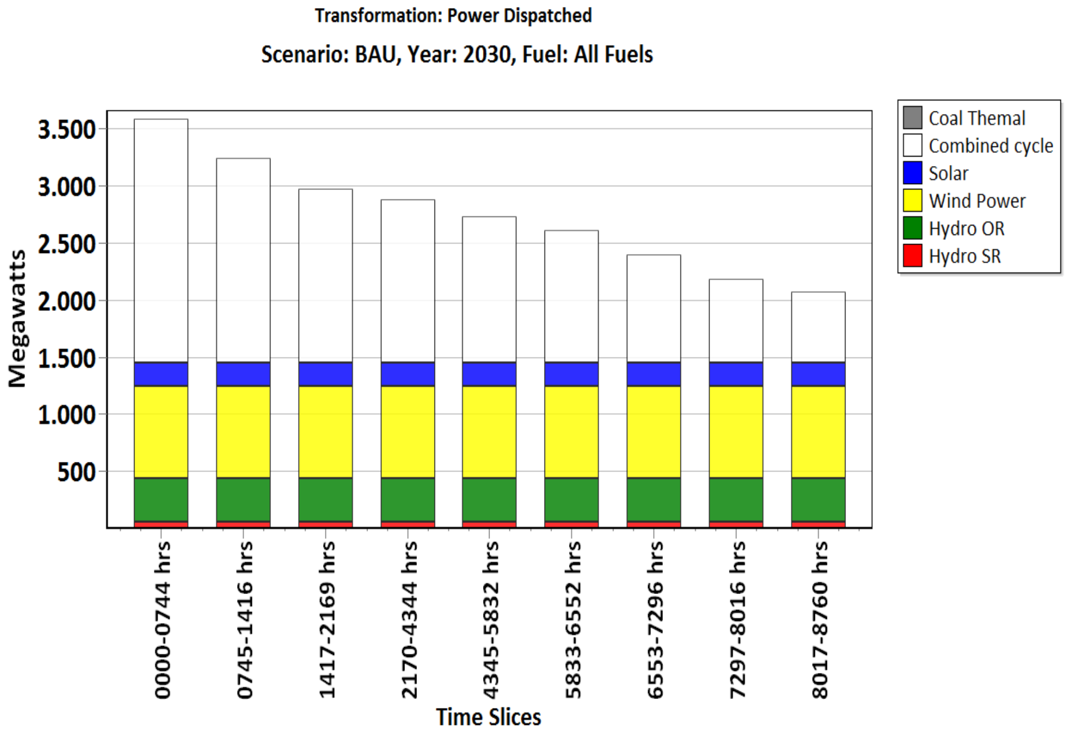


Figure 36. Load curve in years 2009 and 2030. BAU scenario.

Regarding heat generation, the evolution can be observed in Figure 37. As cogeneration generates always more than 99.6% of the heat, electricity produced as a by-product is related to heat. Both heat and electricity generation increase 16% from year 2008.

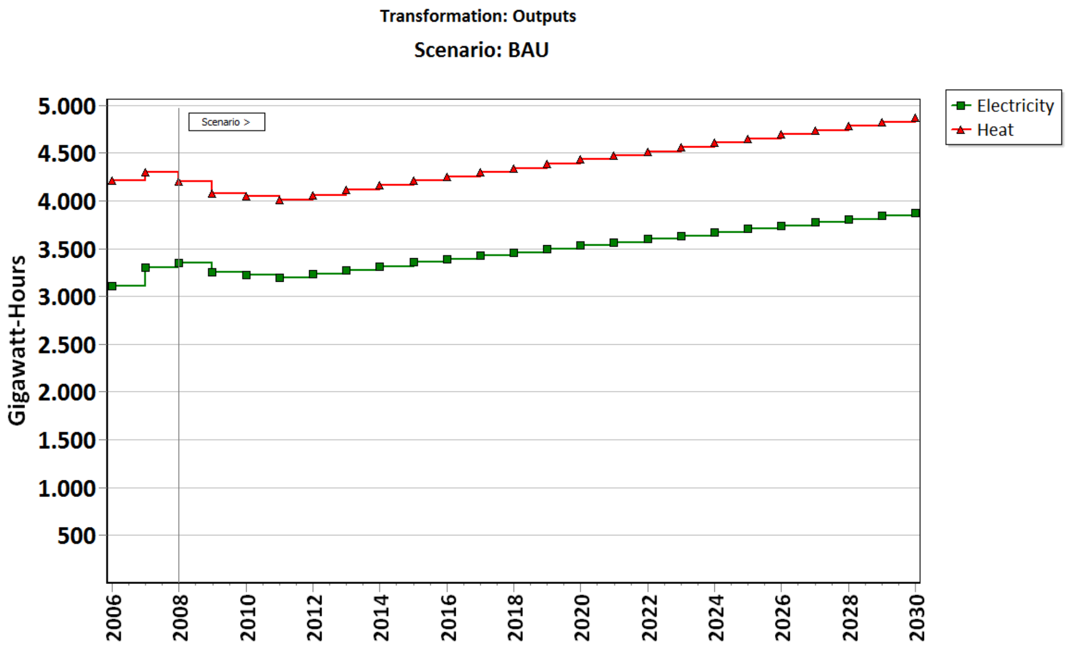


Figure 37 Heat generation and electricity associated. BAU scenario.

Technology shares in 2030 when cogeneration is included in electricity generation are included in Table 8. Combined cycle is the most important technology. However, renewable technologies without including biomass used in cogeneration 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.

Table 8 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. However, even with this increase biomass is the third less used fuel, after crude oil and solid fuels. Electricity consumption grows 23% during this period. Natural gas increases its final demand in 20%, and heat 16%. These 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 1895 ktoe in 2030.

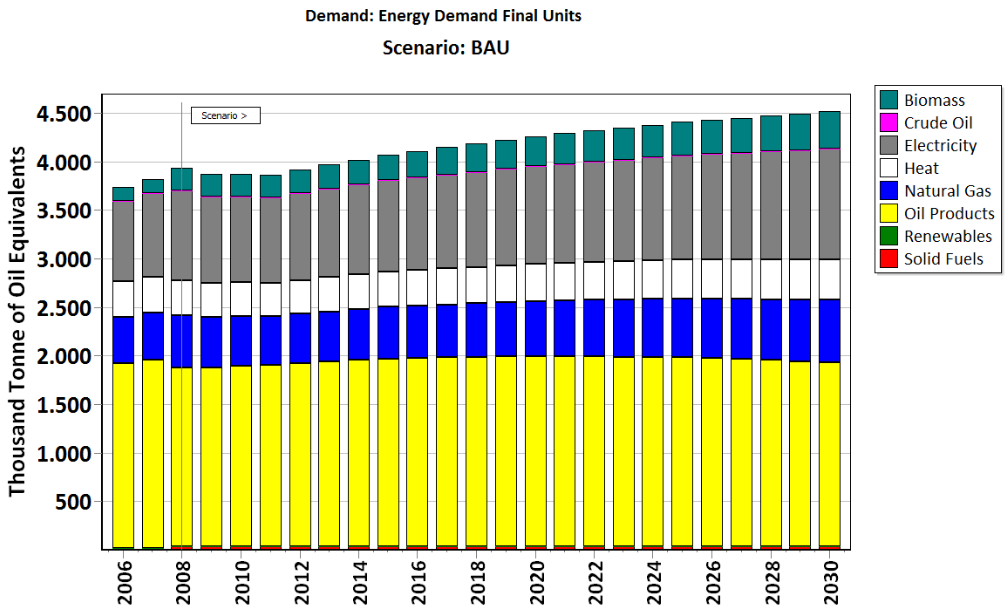


Figure 38 Final energy consumption by sources. BAU scenario

Regarding final consumption by sector, the evolution 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%, mainly driven by electricity and natural gas consumption. 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.

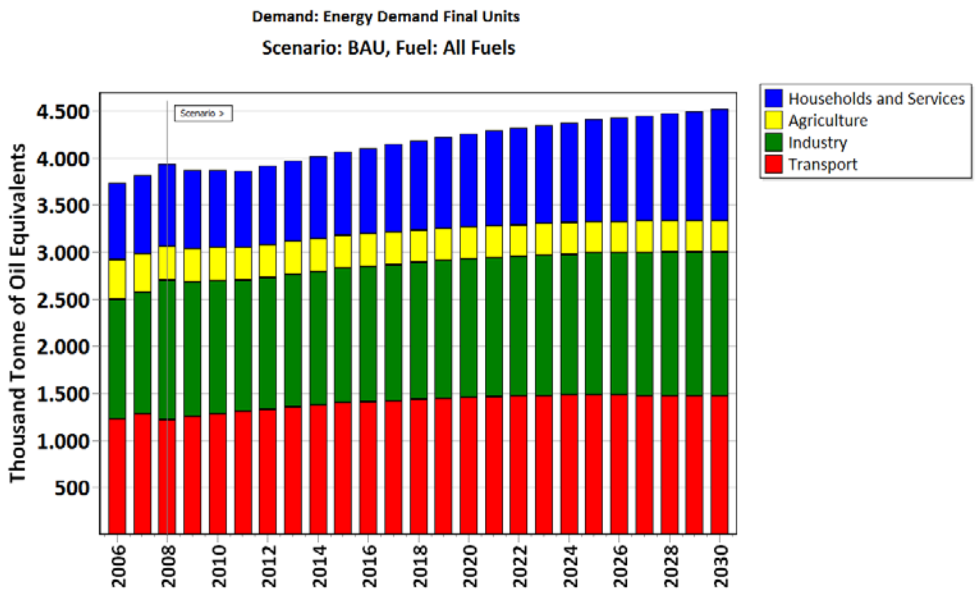


Figure 39 Final energy consumption by sector. BAU scenario.

A slightly different situation is observed in the industry sector. The energy consumption increases only 4% from 2008. This is due to economical 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.

8.2 Coal priority

In this section the main differences between the BAU scenario and the COAL scenario will be explained. Note that all the results, if not specify, show absolute differences between COAL and BAU scenario.

The first important result in the COAL scenario is the increase in use of coal and the decrease in use of natural gas comparing to the BAU scenario, as shown in Figure 40. Note that one ktoe of natural gas in substituted by 1.4 ktoe of coal. Besides, there is a very small decrease of renewable resources and hydropower, around 10 ktoe until 2018, when coal power is more important. After 2018, some years there is less need of renewable energy (mainly wind power), around 23 ktoe each year. Also a small increase in diesel (which is used in coal power plants) in observed, always bellow 1 ktoe.

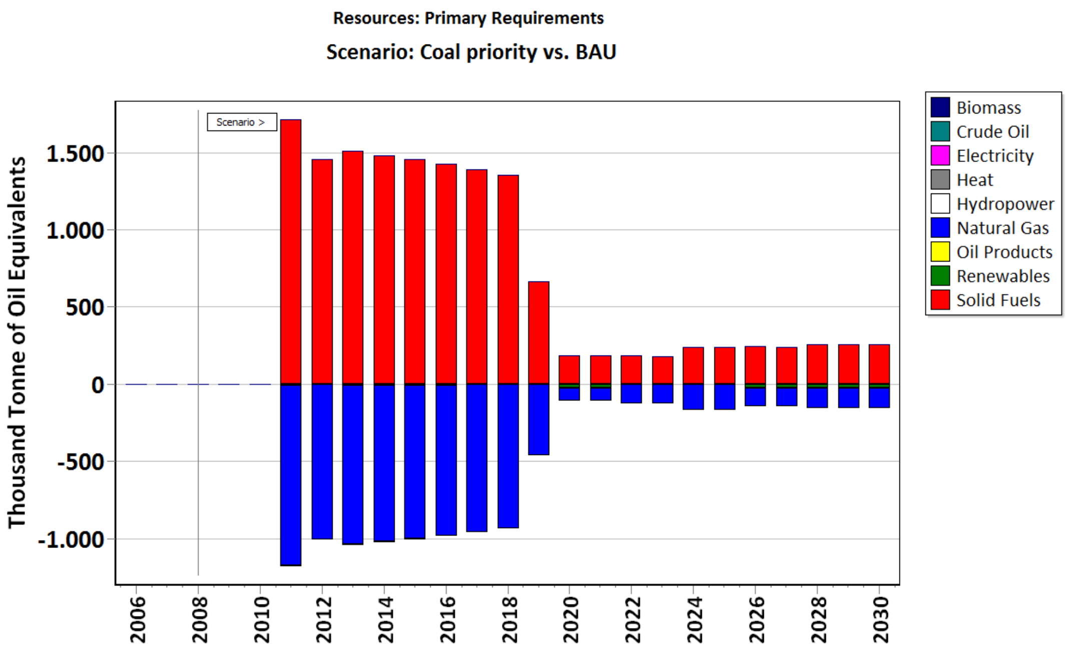


Figure 40 Difference in primary requirements between COAL and BAU scenarios.

Regarding the transformation branch, the only difference is in the electricity generation. The results of electricity generation by technologies are very similar to the primary requirements results. In this case, coal thermal substitutes mainly CC generation, from a maximum of 7200 MWh in 2011 to a minimum of 755MWh in 2023. After that year the substitution stabilised around 1000 MWh. Renewable energy generates also less energy than in the BAU scenario. The most affected technology is wind power, with the most important differences of -264 MWh in 2020, 2021 and from 2026 to 2030. These differences are caused by a decrease of the capacity installed in wind. In each year (2020, 2021, 2016, 2017, 2028, 2029 and 2030) 100 MW less are installed compared with the BAU scenario. The reason for this is that coal power plants are available more time than wind power and therefore LEAP considers that less reserve margin is required.

Finally, the last main difference with the BAU scenario is the power dispatched. While in 2009 is the same as in the BAU, since changes were not introduced yet, in 2011 the differences are important in all the time slices. Figure 40 shows the differences between COAL scenario and BAU scenario in year 2011, the first year when coal power plants are given priority. Coal thermal power plants substitute CC in peak and medium loads, and a small amount of renewable in the base load hours. In year 2030, coal thermal power plants are dispatched as base load with a constant amount of 123 MW (see Figure 42). With those megawatts, at every time slice during year 2030 coal thermal substitutes want in the BAU scenario were 30 MW of wind power and 93 MW of CC.

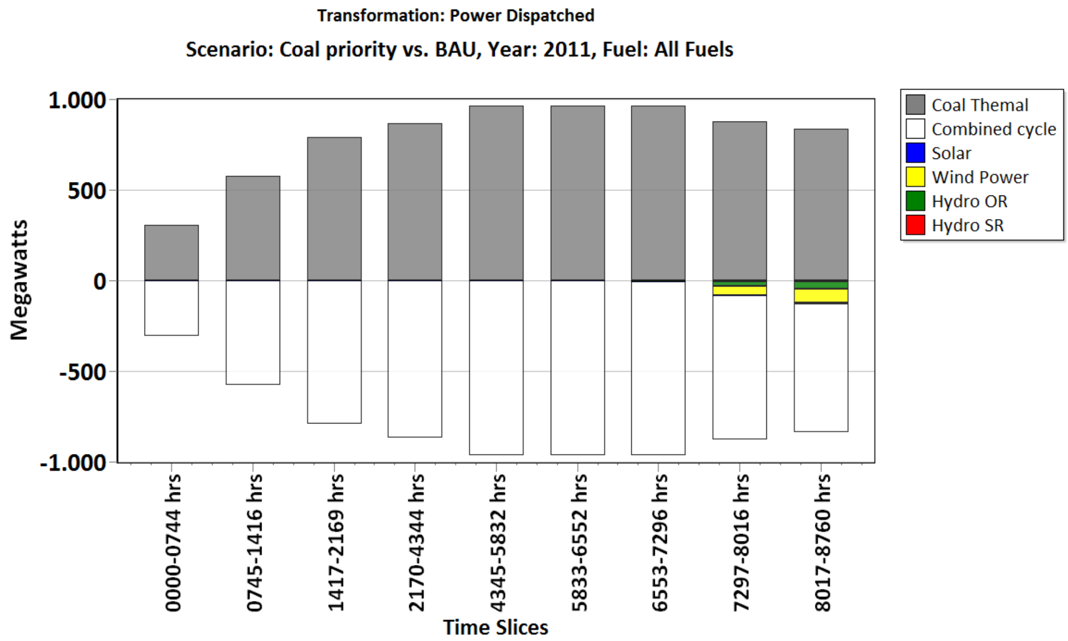


Figure 41 *Difference in power dispatched in 2011 between COAL scenario and BAU scenario.*

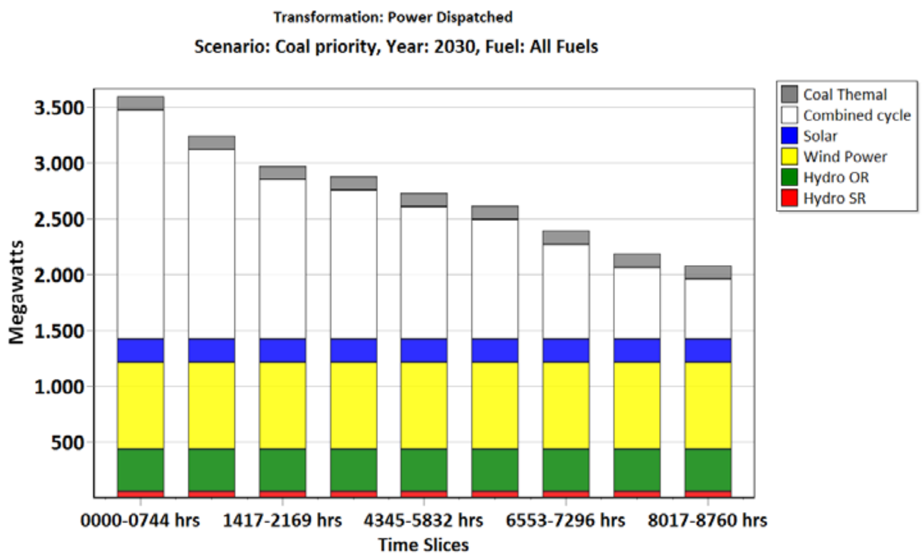


Figure 42 Power dispatched in 2030 in the COAL scenario.

8.3 Renewable electricity

In this section the main differences between the BAU scenario and the REN scenario will be explained. Note that all the results, if not specify, show absolute differences between REN and BAU scenario.

Changes in the REN scenario occurs in the same parts of the system as in the COAL scenario. Energy inputs demand changes from year 2019, when in the REN scenario solar and wind power plants are built to substitute coal thermal, while in the BAU scenario CC using natural gas can also be built. For each unit of renewable energy consumed in the REN scenario, 1.9 units of natural gas that were used in the BAU are not consumed. This represents 16666 ktoe of natural gas that does not need to be imported in Aragón from 2019 to 2030.

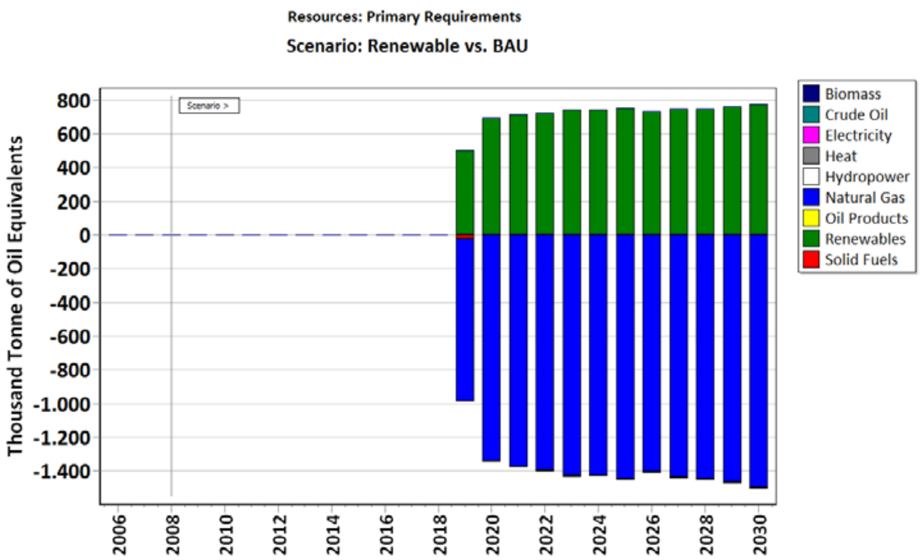


Figure 43 Differences in energy inputs requirements between REN and BAU scenario.

The rest of the differences are similar: solar and wind power substitute coal and natural gas for electricity generation. Analysing the power dispatched, it can be observed how in 2019 renewable energy adds base load in a way that substitutes natural gas during all time slices and coal at peak load hours (see Figure 44). The base load in 2019 calculated for this scenario is basically renewable energy: 1050 MW of wind power, 364 MW of solar power, 435 MW of hydropower and only 15 MW of CC. During year 2030, CC only needs to be dispatched two thirds of the year for peak loads, see Figure 45. During 6552 hours during 2030, solar and wind power substitute 1100 MW of CC that were dispatched in the BAU scenario. The rest of the year, solar and wind power substitutes all the CC that was dispatched in the BAU scenario.

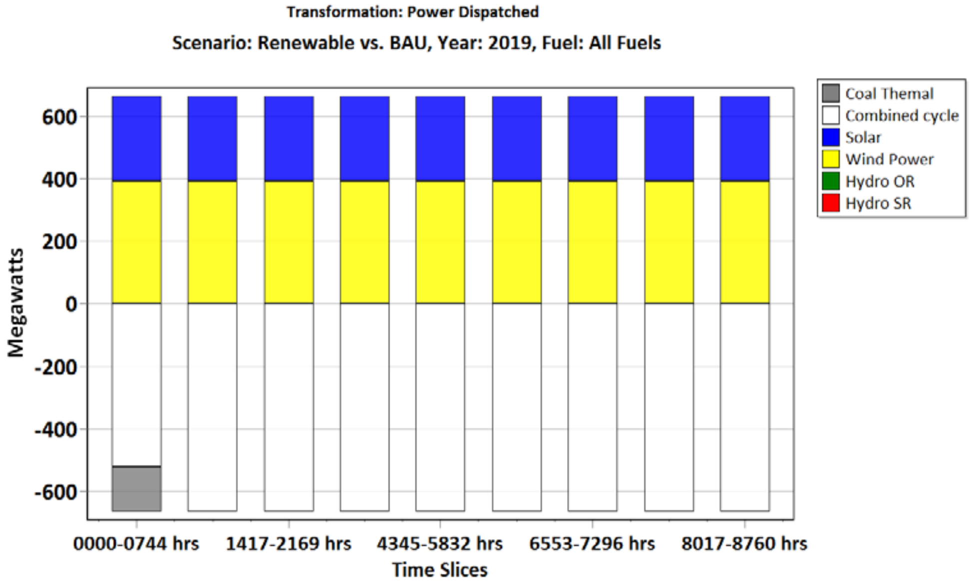


Figure 44 Differences in energy inputs requirements between REN and BAU scenario.

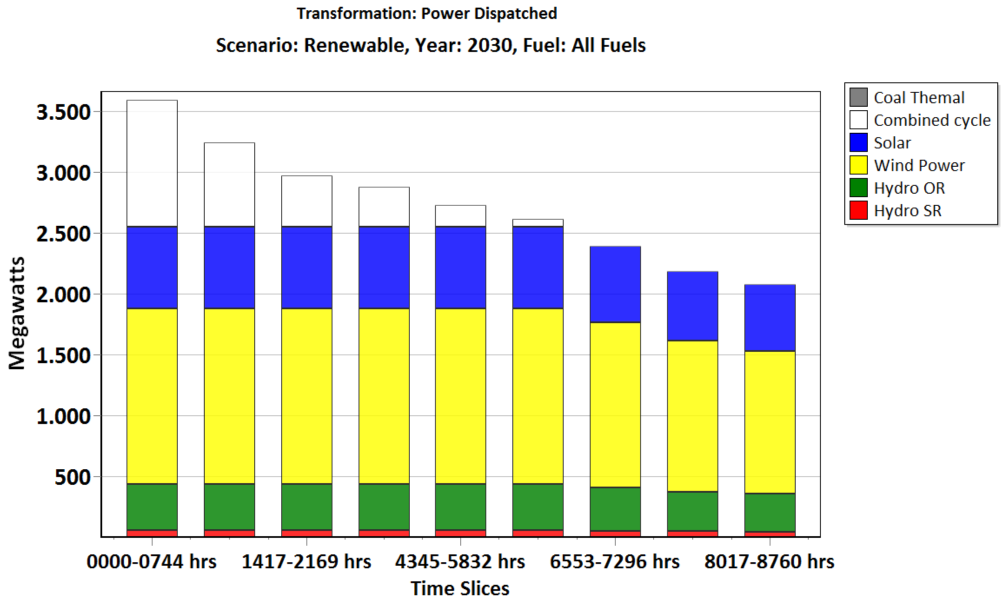


Figure 45 Power dispatched in year 2030 in the REN scenario.

8.4 Electric cars

In this section the main differences between the BAU scenario and the ELECAR scenario will be explained. Note that all the results, if not specify, show absolute differences between REN and BAU scenario.

As it can be observed in Figure 46, the introduction of the electric car increases the demand of fuels needed to generate electricity, while the demand of oil products decreases. This effect is added to the changes in the REN scenario. During the entire period 2098 ktoe of oil products and 16 836 ktoe of natural gas that were used in the BAU scenario are substituted by 3 936 ktoe of solar energy and 5 231 ktoe of wind power. In total, imports decrease 18 973 ktoe from the BAU scenario.

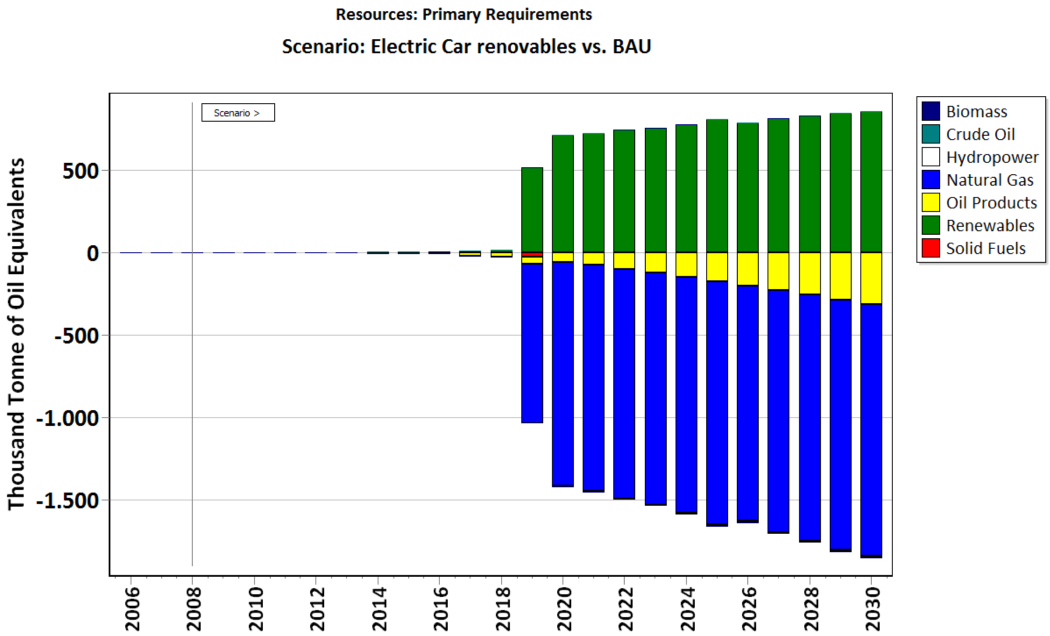


Figure 46 Difference in energy inputs requirements between ELECAR and BAU.

In the transformation branch the changes occur again in the electricity generation part. The first changes are observed in the added capacity (see Figure 47). There are no changes from the BAU scenario until 2019, when coal power plants are closed. From 2019, 3 240 MW more than in the BAU scenario are installed. There is 2 700 MW of solar energy and 2 300 MW of wind power more, and 160 MW of coal thermal and 1600 MW of CC are "saved" from the BAU scenario.

Regarding electricity generated by technology, Figure 48 shows the decrease of CC. This situation is similar to the REN scenario. In total 430 ktep more than in the BAU scenario are generated Therefore there are also differences in the power dispatched. The first year when differences occur is 2011. Nevertheless the differences that year are small. These differences continue increasing every year, and finally the power dispatched in year 2030 is shown in Figure 49. Base load is covered by renewable energy, which substitutes 1100 MW during the year.

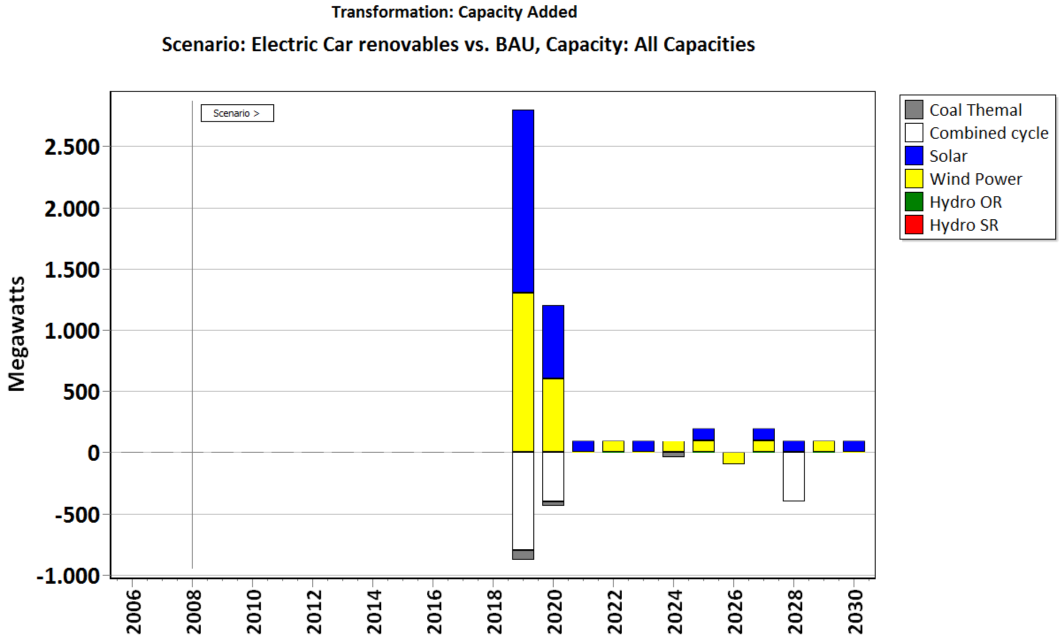


Figure 47 Difference in capacity added between ELECAR and BAU.

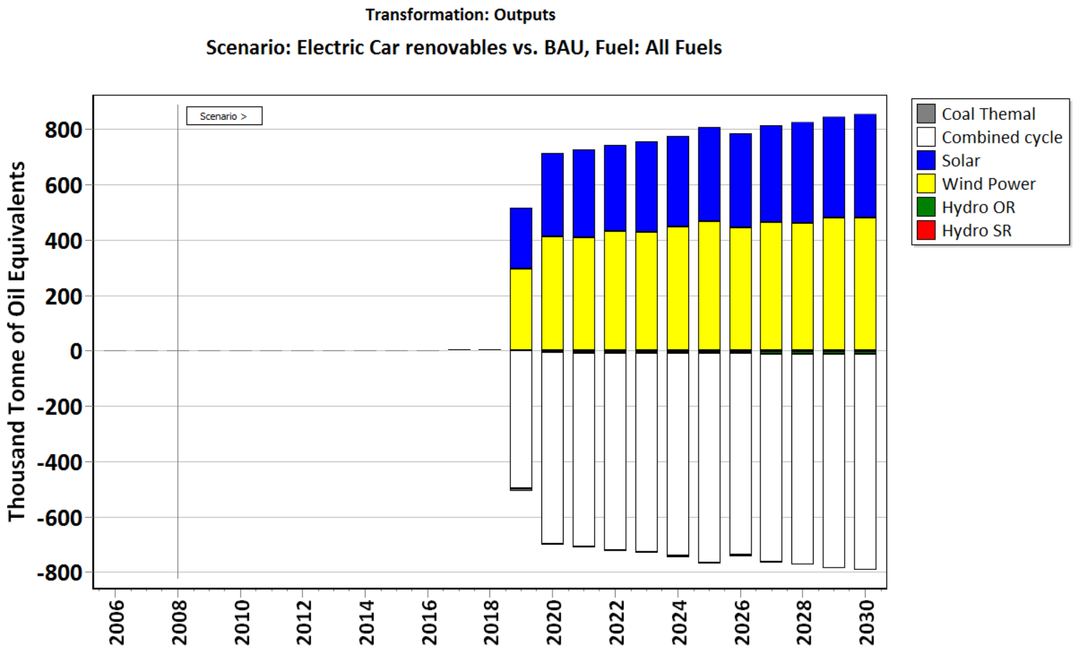


Figure 48 Difference in electricity generation by technologies between ELECAR and BAU.

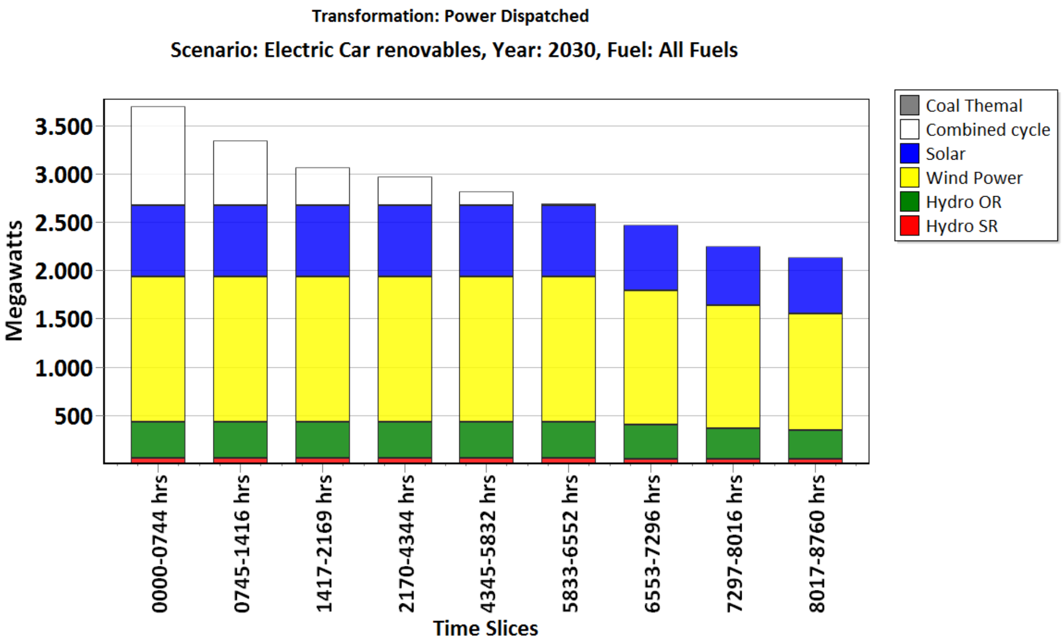


Figure 49 Power dispatched in 2030 for the ELECAR scenario.

Finalmente, en la rama de demanda de energía final se sustituyen parte de los derivados del petróleo, utilizados en el sector Transporte, por electricidad (ver **¡Error! No se encuentra el origen de la referencia.**). En 2030, la demanda de electricidad del escenario ELECAR supone el 11% de la demanda total en el sector transportes y la de derivados del petróleo el 82%, lo que se puede comparar con el 1.4% que representa la electricidad en el año 2008 y el 97% que representan los derivados del petróleo en el año 2008. Este cambio ocurre únicamente en el sector Transporte y no afecta a los demás sectores.

Finally, the final energy consumption change involves the substitution of a part of the oil products used in the transportation sector by electricity, as represented in Figure 50. 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%. Changes in the consumption occur in the transportation sector, and it does not affect the rest of the sectors.

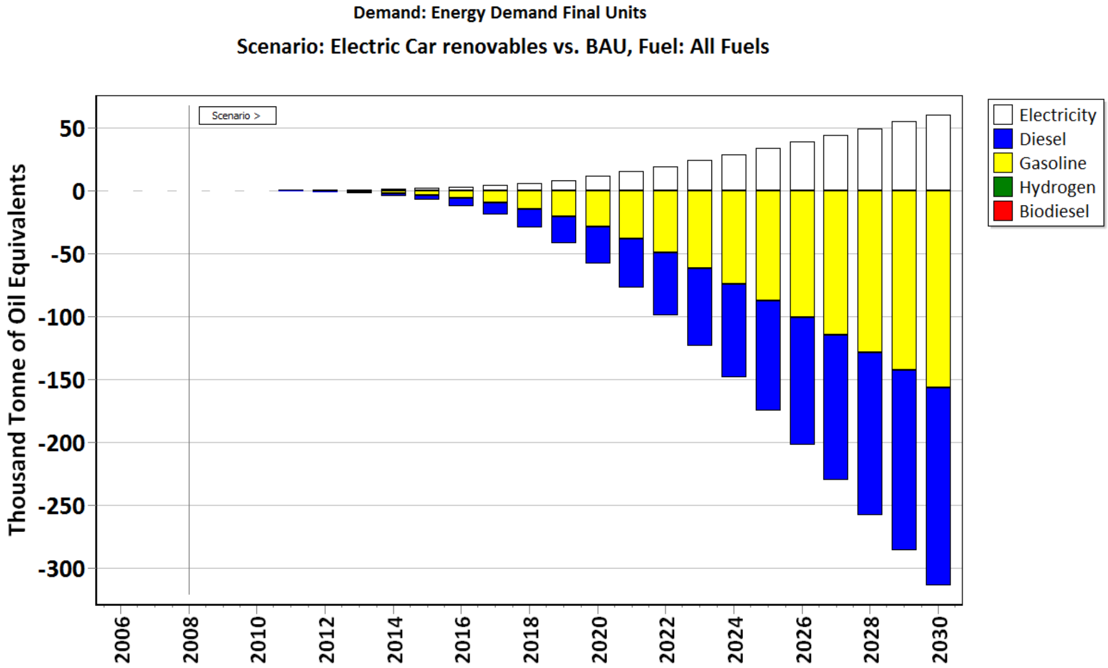


Figure 50 Differences in final energy demand between ELECAR and BAU.

8.5 Emissions

The Global Warming Potential (GWP) allocated to demands and divided by sectors for the BAU scenario is represented in Figure 51. From the emissions in the BAU scenario, it can be observed that the sectors with more emissions are the transportation sector and the industry sector. As explained before, 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 ktone of CO2 equivalents. During the first years of the period, it is due to the decrease of energy consumption caused by the economical 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. Emissions caused by use of coal decrease 95%, as the consumption of coal decreases. On the other hand, emissions caused by use of natural gas increase 39%, emissions caused by biomass increase 17% and emissions caused by oil products, 4%.

Figure 52 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 ktonne of CO2 equivalents higher than in the BAU scenario. The ELECAR scenario represents the opposite situation. The total savings in this scenario are 28 936 ktonne of CO2 equivalents. The REN scenario has also important reduction of emissions in comparison with the BAU scenario, 22 754 ktonne of CO2 equivalents less.

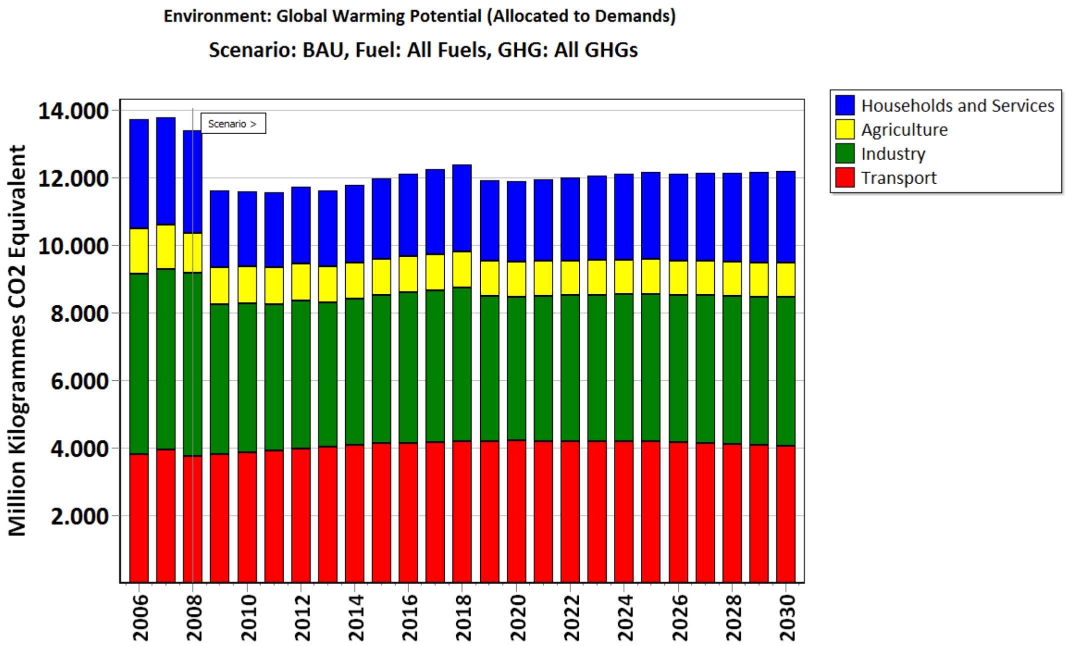


Figure 51 Global warming potential allocated to demands. BAU scenario

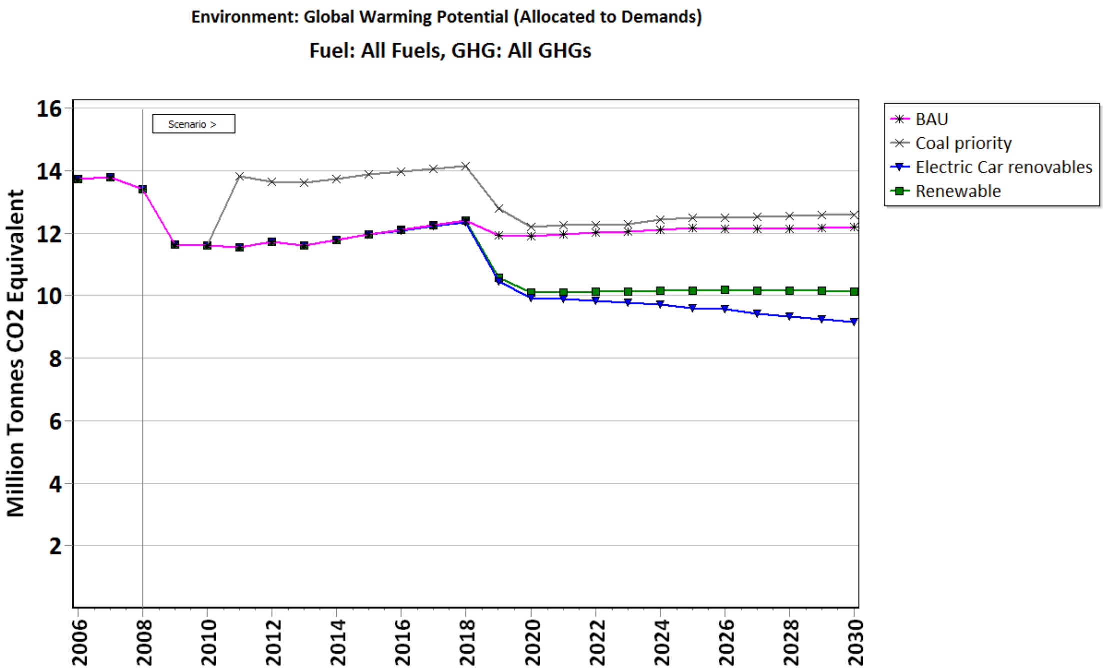


Figure 52 Global warming potential allocated to demands for BAU, COAL, REN and ELECAR scenario.

8.6 Cost

In this section the cost-benefit analysis calculated by LEAP is explained. This analysis does not pretend to be an analysis of the economical feasibility of each scenario. Rather, LEAP provides a tool to compare scenarios and decide which are sociable acceptable. As explained in section 7.1 cost estimates include capital cost, operation and maintenance and fuel cost for electricity and heat generation technologies. An estimation of policy cost to promote electric cars is also included. The discount rate is 10%, since data from the European Union use that value. All monetary data are discounted to 2006.

Costs with no discounting method applied are shown in Figure 53. 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 CO2 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 reason is the opposite, the renewable technologies prices are the highest. The REN scenario has a similar cost for the same reason. However, it must be taken into account that a higher penetration in the market would mean that the prices of the technologies would decrease. Subsidies to renewable energy, electric cars or coal that could be needed to achieve the scenario are also not included.

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.

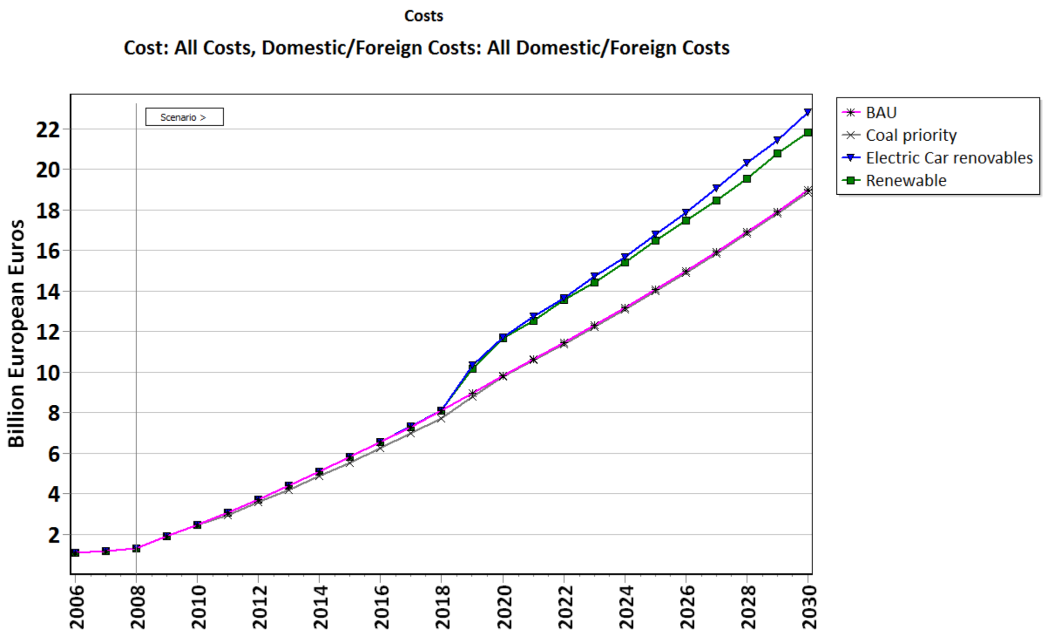


Figure 53 Cost for BAU, COAL, REN and ELECAR scenario.

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 5 332 million Euros more expensive than the base case.

9 Discussion

In this section a discussion is presented. The discussion includes comments about the results of the study and about the difficulties and positive aspects found during the process.

9.1 Data and information

Most of the 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. The excel document provided by the DGA with detailed information was also very useful to understand the system. However, when more detailed data is needed it is not easy to find. This data is not published by the Energy department in the DGA, but it is available in the IAEST webpage under different categories. Under the energy category, only a few indicators and data are found. Under the environmental category, environmental and energy data are mixed, leading to confusion. 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. Anyway, the different books include detailed data about the energy system of the region. This level of detail is important to maintain to carry on energy planning. The reports published every six months are good as an overview of the system, but the level of detail is not enough to develop a satisfactory energy plan, especially regarding final energy demand.

An important problem is the lack of data at regional level that is necessary and it is only available at national level. When decisions are taken at national level, it is difficult or even impossible to find some data at regional level.

Disagreements between data were also found. For example, some final energy consumption values are different in the RES-diagrams published in the Internet and in the RES-diagrams published in books. The problem happens for several years. 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.

Nevertheless, availability of official data is good. 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. As the energy sector is important in Aragón, an organization that focuses in the sector could be useful. The idea of an Energy Agency of Aragón has been already proposed in the Energy Plan 2005-2012. However it has not yet been created.

9.2 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 (UNESA, 2007), in the proposal of the government (Ministery of Economy and Treasury, 2010a) and in the plan for the electric vehicle (Ministery of Economy and Treasury, 2010b). 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. At regional level, the issue is even more difficult, since there are no plans published for Aragón by any company.

Since today only transportation 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. It is clear that 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.

Classification of primary energy and secondary energy in the energy data from the DGA is also slightly problematic. Oil products are included in primary energy because there are no refineries in Aragón. To handle this situation, in this report the name "energy inputs" is used instead of primary energy, which is used in the DGA documents. A more important 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, to know if it is desirable to increase its presence, detailed data about the transformation processes that produce of biofuels and hydrogen is necessary. With the information available it is not possible to built scenarios including an important presence of any of these fuels. In order to gather data regarding this fuels different companies were contacted, with no answer.

9.3 LEAP and results

LEAP has been a useful tool, but not without problems. LEAP performs very well as an accounting program, producing useful diagrams, tables and graphs. Nevertheless, it contains bugs. These bugs are frequently fixed by the developers and they are usually not important. 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. New versions are released every month approximately. 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 is problematic when there is a hard deadline that has to be met.

Logistics curves provide two important results, firstly regarding electricity consumption and secondly regarding the difference between installed capacity and electricity production. Using the logistic curve, electricity consumption in 2030 is 50% higher than the result provided by LEAP. The logistic curve does not introduce efficiency measures or other factors, while data introduced in LEAP does. As the introduction of a new technology changes the logistics curves for installed capacity and electricity production, changes in the logistic curve can be caused by introduction of efficiency measures, changes in life style, introduction of new technologies in the demand side, etc. Some of these factors are included in the data introduced in LEAP, and not in the logistic curve. This difference in results shows how different can be the results 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.

When analysing the difference between installed capacity and electricity production, a surplus of installed capacity is observed. The introduction of renewable technologies are a cause for this, since the capacity factor of wind power and solar PV is lower than for the rest of the technologies. However, in Aragón the main reason is that there is installed capacity without use. CC is used as peak load, but is the technology with more installed capacity in Aragón. At the same time, coal thermal has decreased its production since the introduction of CC, 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 disappears, since coal thermal power plants become reserve capacity. At the same time, new capacity is introduced endogenously 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 is 50% a local resource. There is a small decrease in the use of renewable energy to produce electricity. Therefore, even when existing coal power plants close, there are more CO_2 emissions. On the other hand, 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 and it has the lowest emissions.

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

Other 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. Grid issues were not included in this study because they cannot be introduced in LEAP.

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. The cost of the different policies that would be necessary to reproduce these scenarios, as well as externalities and societal cost, could be estimated and introduced in LEAP in future studies. Currently only the cost of the policy to promote electric car until 2014 is know. However, this part of the program could be very useful when focusing in different environmental and social policies and carrying out energy plans, 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 CO2 is needed for the renewable technologies to be competitive in the market. On the other hand, if renewable technologies penetrate more in the market, they would be cheaper than expected in the European forecasts. The evolution of the cost of using renewable energy when the penetration in the market is higher should be considered in future studies.

10 Conclusions

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

- Most of the information can be found in the Internet.
- Data about the energy system in Aragón is rather good if a high level of detail is not needed.
- Some detailed data is not well organized, and there are data gaps.
- An organization could be created to avoid this problems and to aproach the energy issues with a system perspective.
- Contacting Spanish energy companies has been very difficult.
- Existing studies about the future energy system in Spain carried out by the government or the companies have a lack of explanations of the assumptions made.
- The fact that the cogeneration facilities are driven by the heat demand is not considered in any of the energy plans taken into account in this study.
- The clasification of done by the DGA is slightly confusing and can lead to mistakes in future plans. Therefore changing the name, for example to ”energy inputs”, is recomended.
- Use of LEAP when there is a hard deadline to meet is not recomended. Nevertheless, it is an excelet tool for accounting propouses and as a first aproach to see effects of changes in the system. The costumer support is very good.
- The logistic curve results in a 50% higher electricity consumption than the one calculated by LEAP.
- There is a surpluss of installed capacity in Aragón.
- In the BAU scenario, natural gas subtitutes coal, which disapears from electricity generation. RCS sector has the major increase in energy demand, while industry and agriculture are supouse to apply efficiency meassures. 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 emisions. The energy security is higher, but both of them are expensive
- No new endogeous 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 posibilities 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.

11 Future studies

Several relevant issues to study in the future have been suggested in this report. They are summarized in the following list:

- To carry out an analysis about the transformation of final energy in useful energy in Aragón
- Study the transportation sector and integrate it in energy planning.
- Include the land use in future energy plans. This is important when renewable energy and biomass are important sources of energy
- The transportation and distribution grids, as well as intermittence of renewable, must be included in future studies.

References

A.P.P.A. 2009. *A.P.P.A (Renewable Energy Producers Asociation) webpage* [Online]. Available: http://www.appa.es/index.php [Accessed 02 2010].

ARAGÓN, G. D. 2000. Estructura Energética de Aragón. Los balances energéticos regionales en el periodo 1984-1997. *In:* DEPARTAMENTO DE INDUSTRIA, C. Y. D. (ed.). Zaragoza: Gobierno de Aragón. Departamento de Industria, Comercio y Desarrollo.

AROCENA, P., CONTÍN, I. & HUERTA, E. 2002. Price regulation in the Spanish energy sectors: who benefits? *Energy Policy,* 30**,** 885-895.

B.O.A 2007. BOA 1825. *In:* ENVIRONMENT (ed.).

B.O.A 2009a. Autorization for an environmental assessment study to the solar thermoelectric plant "Belver de Cinca C". Zaragoza: DGA.

B.O.A 2009b. Information about the power plant "Ibersol Teruel". *In:* DEPARTAMENTO DE INDUSTRIA, C. Y. D. (ed.). Zaragoza.

B.O.E 2009. REAL DECRETO 485/2009. *In:* MINISTERIO DE INDUSTRIA, C. Y. T. (ed.) *82.*

B.O.E 2010. REAL DECRETO 134/2010. *In:* MINISTERIO DE INDUSTRIA, C. Y. T. (ed.) *51.*

B.O.E. 2008. *REAL DECRETO 1578/2008*. *In:* MINISTERIO DE INDUSTRIA, C. Y. T. (ed.) *234.*

CNE 2009. Informe macro sobre la demanda de energía eléctrica y gas natural, y su covertura. Año 2009. Comisión Nacional de Energía.

CNSE 1997. Ley del sector eléctrico. *In:* CNSE (ed.) 2º Edition ed. Madrid.

COMMED. 2010. *Home: COMMEND* [Online]. Stockholms Environmental Institute. Available: http://www.energycommunity.org/ [Accessed].

CHARLES HEAPS, PETER ERICKSON, SIVAN KARTHA & ERIC KEMP-BENEDICT 2009. Europe's Share of the Climate Challenge. Domestic Actions and International Obligations to Protect the Planet. Stockholm Environment Institute.

CHARLES HEAPS, P. E., SIVAN KARTHA, ERIC KEMP-BENEDICT 2009. Europe's Share of the Climate Challenge. Domestic Actions and International Obligations to Protect the Planet. Stockholm Environment Institute.

DEL RÍO GONZÁLEZ, P. 2008. Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms. *Energy Policy,* 36**,** 2917-2929.

DEL RÍO, P. & UNRUH, G. 2007. Overcoming the lock-out of renewable energy technologies in Spain: The cases of wind and solar electricity. *Renewable and Sustainable Energy Reviews,* 11**,** 1498-1513.

DGA 2000. *Estructura Energética de Aragón. Los balances energéticos regionales en el periodo 1984-1997,* Zaragoza, Gobierno de Aragón. Departamento de Industria, Comercio y Desarrollo.

DGA 2005a. *Los Balances Energéticos Regionales en el periodo 1998 - 2004. Datos y análisis para una estrategia energética,* Zaragoza, Gobierno de Aragón. Departamento de Industria, Comercio y Turismo.

DGA 2005b. *Plan Energético de Aragón, 2005-20012,* Zaragoza, Gobierno de Aragón. Departamento de Industria, Comercio y Turismo.

DGA 2006. Boletín de coyuntura energética en Aragón num 16, segundo semestre 2005. Zaragoza: Departamento de Industria, Comercio y Turismo.

DGA 2007. Boletín de coyuntura energética de Aragón num 18, segundo semestre 2006. Zaragoza: Industria, Comercio y Turismo.

DGA 2008. Boletín de coyuntura energética en Aragón num 20, segundo semestre 2007. Zaragoza: Departamento de Industria, Comercio y Turismo.

DGA 2009a. Boletín 22, datos excel. Zaragoza.

DGA 2009b. Boletin de coyuntura Energética en Aragón num 22, segundo semestre 2008. *Departamento de Industria, Comercio y Turismo. Gobierno de Aragón.* Zaragoza: Departamento de Industria, Comercio y Turismo.

DGA 2009c. Boletín de coyuntura energética en Aragón num 21, primer semestre 2008. *In:* DEPARTAMENTO DE INDUSTRIA, C. Y. D. (ed.). Zaragoza.

DGA 2010. BOA. Autorization thermal power plant in Mequinenza. *In:* DEPARTAMENTO DE INDUSTRIA, C. Y. T. (ed.). Zaragoza.

EUROPEAN COMMISSION 2007. Commission staff working document - EU Energy Policy Data.

FORO DE LA INDUSTRIA NUCLEAR ESPAÑOLA 2010. Energía 2010. Madrid.

GERMÁN, L. 1998. *ERZ (1910-1990). El desarrollo del sector eléctrico en Aragón,* Zaragoza, Luis Germán, Instituto Fernando el Católico, ERZ.

HEAPS, C., ERICKSON, P., KARTHA, S. & KEMP-BENEDICT, E. 2009. Europe's Share of the Climate Challenge. Domestic Actions and International Obligations to Protect the Planet. Stockholm Environment Institute.

I.E.A 2009. Global Renewable Energy. Policies and measures, Spain.

IAEST. 2009. *Instituro Aragones de estadística webpage* [Online]. Available: http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_00/IAEST_001DB/IAEST_001DB_INDICE/IAEST_001DB09/IAEST_DatosB%C3%A1sicos09.pdf [Accessed].

IAEST. 2010a. *Instituto Aragones de Estadística web page* [Online]. Available: http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_04/IAEST_0413 [Accessed].

IAEST. 2010b. *Instituto Aragonés de Estadística webpage* [Online]. Available: http://portal.aragon.es/portal/page/portal/IAEST/IAEST_0000/IAEST_03/IAEST_0301/IAEST_030100 [Accessed].

IDAE. *Energías Renovables - IDAE, Instituto para la diversificación y Ahorro de la Energía* [Online]. Madrid. Available: http://www.idae.es/index.php/mod.pags/mem.detalle/idpag.16/relcategoria.1021/relmenu.41 [Accessed 2010].

IDAE 2009. Energía solar termoeléctrica. Situación actual. *In:* FRESNEDA, P. P. P. B. A. (ed.).

IDAE. 2010. *MOVELE, proyecto de movilidad eléctica* [Online]. Instituto para la diversificación y ahorro de energía. Available: http://www.idae.es/index.php/mod.pags/mem.detalle/relcategoria.1029/id.490/relmenu.52 [Accessed].

INE 2010. Home: Instituto Nacional de Estadística. *Instituto Nacional de Estadística - webpage.* Instituto nacional de estadística.

MINISTERIO DE FOMENTO 2008. Aeropuerto de Zaragoza. Informe de gestión ambiental.

MINISTERY OF ECONOMY AND TREASURY 2010a. Acuerdo político para la recuperación del crecimiento económico y la creación de empleo. Propuestas del gobierno.

MINISTERY OF ECONOMY AND TREASURY 2010b. Estrategia integral del vehículo eléctrico.

MIR, M. C. 1999. Evaluación de los Planes Energéticos Nacionales en España (1975-1998). *Revista de Historia Industrial,* 15.

ONLINE, G. E. A. *La industria aragonesa. Localización de la industria en la provincia de Huesca.* [Online]. Zaragoza. Available: http://www.enciclopedia-aragonesa.com/monograficos/geografia/industria_aragonesa/localizacion_huesca.asp [Accessed 2010].

PARLIAMENT, E. 2001. Directive 2001/77/EC. *In:* UNION, E. P. A. T. C. O. T. E. (ed.).

PROF. P. CAPROS, DR. L. MANTZOS, V. PAPANDREOU & TASIOS, N. 2008. European Energy and Transport. Trends to 2030. Update 2007. *In:* COMMISSION, D. G. F. E. A. T. E. (ed.). Belgium.

PROF. P. CAPROS, D. L. M., V. PAPANDREOU, N. TASIOS 2008. European Energy and Transport. Trends to 2030. Update 2007. *In:* COMMISSION, D. G. F. E. A. T. E. (ed.). Belgium.

PUBLIC LIBRARY OF ANDORRA. 2010. *Local information from Andorra, Teruel* [Online]. Available: http://www.biblioteca-andorra.com/cronica_andorra.php [Accessed 27 May 2010].

REE 2009. Avance del informe del sistema eléctrico español 2009. *In:* ESPAÑA, R. E. D. (ed.). Madrid.

REE. 2010. *Electricity grid in 2010 in Aragón* [Online]. Available: www.ree.es [Accessed 2010].

REVE. 2009. *Home: REVE* [Online]. Codarfel. Available: http://www.evwind.es/index.php [Accessed].

Author. 2009. La futura central térmica de Méquinenza suscita oposición en varios pueblos leridanos. *Heraldo de Aragón*.

SPANISH NATIONAL ENERGY COMISION. 2010. *Spanish legislation on special regime. Spanish National Energy Comision* [Online]. Madrid. [Accessed].

UNESA 2004. El sector eléctrico a través de UNESA (1944-2004). *In:* UNESA (ed.). Madrid.

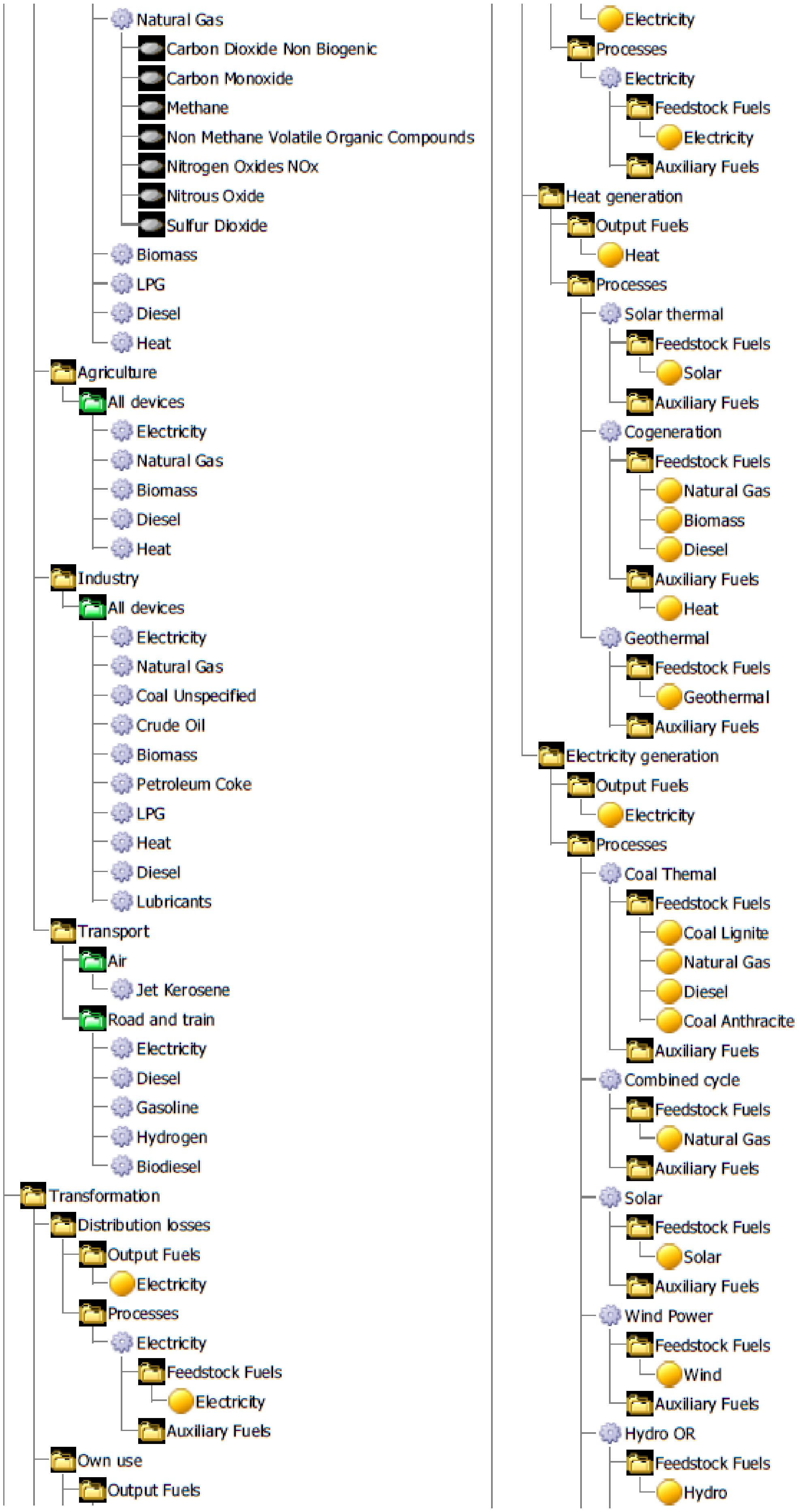
UNESA 2007. Prospectiva de generación eléctrica 2030. Madrid: Asociación Esñola de la Industria Eléctica UNESA.

UNRUH, G. C. 2000. Understanding the carbon lock-in. *Energy Policy,* 28**,** 817-830.

Annex 1. LEAP tree structure

The tree structure used to organize data in LEAP is presented in the following pages.

- Key Assumptions
  - Demographic
    - population
    - households
    - household size
  - Economy
    - GDP Spain
    - GDP per capita Aragon
    - GDP Aragon
    - Value Added
      - Agriculture
      - Industry
      - Services
      - Structure VA Spain
        - VA Industry
        - VA services
        - VA Agriculture
      - Structure VA Aragón
        - VA Agriculture
        - VA Industry
        - VA Services
      - Industry VA percentages
        - Construction
        - Food Industry
        - Textil
        - Wood Industry
        - Paper
        - Chemistry
        - Plastic
        - Non metalic minerals
        - Metal
        - Machinery
        - Electronics
        - Cars manufacture
        - Others
  - Fuel Final Demand
    - Electricty
      - Households and services
      - Agriculture
      - Industry
      - Transport
    - Natural Gas
      - Households and services
      - Agriculture
      - Industry
    - Heat
      - Households and services
      - Agriculture
      - Industry
    - biomass
      - Households and services
      - Agriculture
      - Industry
    - Biodiesel
      - Transport
    - Fuel oil
      - Industry
    - Crude oil
      - Industry
    - Coal
      - Industry
    - Gasoline
      - Transport
    - Diesel
      - Households and services
      - Agriculture
      - Transport
    - LPG
      - Households and services
      - Industry
    - Petroleum Coke
      - Industry
    - Kerosene
      - Transport
    - Other energy fuels
      - Industry
    - Hydrogen
      - Transport
  - Final Demand Sectors
    - Households
    - Industry
    - Agriculture
    - Transport
    - Total demand
    - Air transport
    - Road and Train transport
  - Transport
    - Air traffic units
    - Yearly registered electric cars
    - Number of electric cars
  - Electricity production share
    - Total Hydro
    - Thermal
    - Cogeneration
    - Combined Cycle
    - Wind
    - Solar PV
  - Spanish electricity demand
- Demand
  - Households and Services
    - All devices
      - Electricity


Natural Gas
Carbon Dioxide Non Biogenic
Carbon Monoxide
Methane
Non Methane Volatile Organic Compounds
Nitrogen Oxides NOx
Nitrous Oxide
Sulfur Dioxide
Biomass
LPG
Diesel
Heat
Agriculture
All devices
Electricity
Natural Gas
Biomass
Diesel
Heat
Industry
All devices
Electricity
Natural Gas
Coal Unspecified
Crude Oil
Biomass
Petroleum Coke
LPG
Heat
Diesel
Lubricants
Transport
Air
Jet Kerosene
Road and train
Electricity
Diesel
Gasoline
Hydrogen
Biodiesel
Transformation
Distribution losses
Output Fuels
Electricity
Processes
Electricity
Feedstock Fuels
Electricity
Auxiliary Fuels
Own use
Output Fuels
Electricity
Processes
Electricity
Feedstock Fuels
Electricity
Auxiliary Fuels
Heat generation
Output Fuels
Heat
Processes
Solar thermal
Feedstock Fuels
Solar
Auxiliary Fuels
Cogeneration
Feedstock Fuels
Natural Gas
Biomass
Diesel
Auxiliary Fuels
Heat
Geothermal
Feedstock Fuels
Geothermal
Auxiliary Fuels
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Output Fuels
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Processes
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Feedstock Fuels
Coal Lignite
Natural Gas
Diesel
Coal Anthracite
Auxiliary Fuels
Combined cycle
Feedstock Fuels
Natural Gas
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Wind
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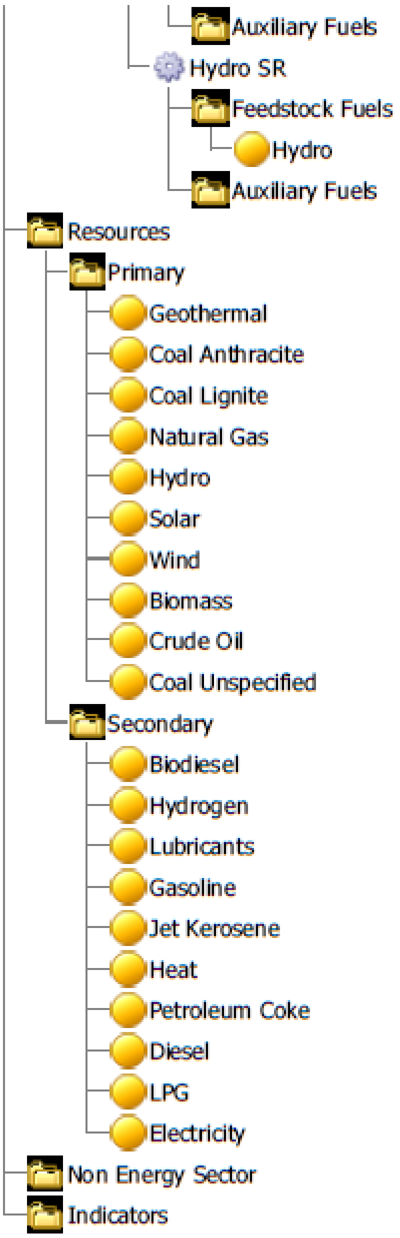
Hydro OR
Feedstock Fuels
Hydro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Hydro SR
Feedstock Fuels
Hydro
Auxiliary Fuels
Resources
Primary
Geothermal
Coal Anthracite
Coal Lignite
Natural Gas
Hydro
Solar
Wind
Biomass
Crude Oil
Coal Unspecified
Secondary
Biodiesel
Hydrogen
Lubricants
Gasoline
Jet Kerosene
Heat
Petroleum Coke
Diesel
LPG
Electricity
Non Energy Sector
Indicators