Vice-Presidential Department
Advisory Council for Sustainable Development

First print: November de 2008

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Print run: 600 copies

Design and printing: Primer Segona serveis de comunicació

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Prologue

Energy moves the world. This sentence, which has been true anytime in human history, is even more appropriate in current times, since almost all activities we do as individuals and as society involves the use of energy sources transformed by man as electricity, fuel or heat. Energy supply is therefore one of the basic elements that each country must ensure, now and in the future, in a clean, secure and sustainable way both in environmental and socio-economic terms.

Energy poses important challenges at all scales and Catalonia does not lie apart to this fact. Energy is a key resource for the present and the future of our country, which interrelates with many other issues: the economic model, industrial development, consumer patterns, mobility systems, available resources, environmental impacts, etc. We can consequently state that a sustainable energy model is one of the keys for sustainable development in Catalonia.

In front of this perspective, the interest of the Advisory Council for Sustainable Development of Catalonia (CADS) was to discuss the quantity and type of energy that is being used to keep Catalan economy working and the main challenges we have ahead according to the current situation. This is what the AMEEC (Analysis of the Energy Metabolism of the Catalan Economy) study has done, using the analogy of metabolism of living creatures applied to the economic system to name an innovative methodology. As you can see when reading this document, the analysis of energy consumption of Catalan economy has turned out to be a complex, yet very interesting, issue as a result of its multiple interactions and its relevance.

This publication is the culmination of a project that started in 2006 as a result of a request to the CADS from the then Conseller Primer (First Counselor), Hble. Mr. Josep Bargalló. The study was possible thanks to the essential support of the Institut d'Estudis Catalans (IEC), which took the task of hiring the research group, and the contribution of the Institut Català de l'Energia (ICAEN), which supplied the study with data about energy use in Catalonia between 1990 and 2005, key to the analysis presented here.

The study is the joint work of an interdisciplinary team led by Dr. Jesús Ramos Martín, economist and PhD in Environmental Sciences from the Autonomous University of Barcelona (UAB). More than ten researches have participated in the study, including well known experts and young researchers, who have contributed with their valuable new perspectives and the results of pioneer doctoral thesis. The study took one full year, and benefited from the support of a follow-up commission, formed by officials of, the Presidency Department –and Vicepresidency since the creation of the department in January 2007-, members of the IEC and the CADS. I would like to thank them all their contribution to guarantee the quality of the work and their expert opinions that enriched the content.

In the CADS we are convinced that the challenges posed by the energy context (foreign dependence, climate change, transport networks, nuclear sources, promotion of renewable energy, etc.) require a serious and in-depth debate; a country debate. The CADS, as a participative, consultative and advisory body of the Catalan Government in the area of sustainable development, wants to contribute to this necessary discussion with capacity of analysis and reflection about the international context, the present and the future, and at the same time proposing defined actions. The study is filled with data that constitute a basis for a rigorous analysis of the different aspects of economy and energy. As mentioned earlier, this is a complex and polihedric issue that can't be solved with one single measure nor from a department or administration, but needs implication from companies, organizations and citizens.

Consequently, this study is an important landmark in a road map that still needs much work to be done. From the CADS we will continue with the reflection and feeding the debate about the energy transition to orientate Government policies and actions, in order that sustainability culture impregnates the decisions and perspectives of future in Catalonia.

Gabriel Ferraté Pascual
President of the CADS

Synthesis

In 2006, the Advisory Council for Sustainable Development commissioned a study entitled Analysis of the Energy Metabolism of the Catalan Economy (AMEEC according to its initials in Catalan). This study looked at the use of energy in Catalonia in the period 1990-2005 and set out the main challenges facing the Catalan economy in the international context of an energy crisis.

The results of this study revealed a close link between economic growth and energy consumption between 1990 and 2005, a period of increasing energy intensity. The energy mix changed slightly: oil was partially replaced by natural gas. Between them, oil and natural gas accounted for three quarters of the primary energy used in the period, and entailed a large amount of CO_2 emissions and heavy external dependency. Use of nuclear energy remained stable, but Catalonia must prepare for the time when its nuclear power stations have to close down. Use of renewable energy in Catalonia is still very limited, something which urgently needs to be rectified if the targets of the Energy Plan for Catalonia are to be achieved.

On the basis of economic, demographic and energy data, the study examined how energy was used in the different sectors of the economy and in the economy as a whole. It showed, among other things, that during the period 1995-2005, labour productivity and the amount of energy used per hour worked remained the same.

In conclusion, energy policy must put in place measures to moderate consumption by means of savings and efficiency strategies at all levels in regard to both final use and transformation. In addition, these measures must be accompanied by appropriate regional development, economic and industrial policies, and advantage must be taken of synergies with actions to combat climate change. The key sectors in which action needs to be taken are transport, construction, taxes and the promotion of alternative energy, as well as fostering technological research and innovation and improvements in the institutional framework for energy.

Introduction

The study Analysis of the Energy Metabolism of the Catalan Economy arose out of concern over the current energy situation, characterised by the Catalan economy's high degree of dependency on fossil fuels and, at the same time, an international context marked by the volatility of, and increases in, the price of oil and other energy sources.

Moreover, the forecast is that this situation will become worse in the medium and long term, as, on one hand, global demand for oil will continue to grow, and, on the other, it looks as though the maximum rate of global petroleum production is about to be reached, a point in time known as *peak oil*. Future energy price rises will therefore cause tensions in the global economic system, affecting especially the countries most dependent on oil, such as Catalonia.

Catalonia is heavily dependent on fossil fuels, more so than other countries. Oil represents nearly 50% and natural gas 25% of its total primary energy consumption, and practically the entire amount of both of them has to be imported. In the medium term, therefore, Catalonia will have to face up to a number of challenges which may be summarised as follows:

1) The competitiveness of the Catalan economy could be threatened by upheavals in the fossil fuels market.
2) The Catalan economy will have to face up to the stress associated with a structural change in the energy sector, as the nuclear power stations age and come to the end of their useful life.
3) The economy must carry out a more general restructuring in order to meet the new challenges resulting from globalisation, such as the enlargement of the European Union with the entry of East European states (which means having to compete with economies possessing much lower labour costs).
4) The demographic dynamics of Catalan society is changing, with the ageing of the population and the arrival of new population. The improved standard of living is leading to increased household energy consumption.
5) At the same time, international commitments to combating climate change will penalise the economies most dependent on fossil fuels due to their obligations to reduce CO_2 emissions.

In this context the AMEEC has employed an innovative methodology, originally called Multi-Scale Integrated Analysis of Societal Metabolism (MSIASM) (Giampietro, 2003), to characterise the Catalan economy in terms of energy in such a way as to obtain a better understanding of the links between the economic, demographic and biophysical variables, the last of these referring to energy consumption.

Applying the MSIASM makes it possible to study, among other things, the relations between the structural changes in different economic sectors, their energy consumption, the evolution of energy efficiency, the evolution of employment in the different sectors, and labour productivity.

However, in order to gain an understanding of the Catalan energy system as a whole, a diagnosis was made of the consumption of each energy vector in the different economic sectors and an analysis carried out of the most important aspects of the Catalan energy system, such as the uses of oil, the electricity generating sector and greenhouse gas emissions resulting from energy consumption, among others.

The AMEEC study had the following aims:

1) To characterise the different sectors of the Catalan economy in terms of their energy consumption.
2) To analyse the historical evolution of primary and final energy consumption in Catalonia.
3) To identify the main problems related to energy consumption in Catalonia and the key factors explaining this consumption.
4) To put forward the strategic lines to be followed in order to improve the energy situation.

The AMEEC study is divided into 12 blocks. On the one hand, they provide the information necessary for the MSIASM (which is done in block 10), while on the other they constitute a comprehensive characterisation of the Catalan energy context.

The titles of the blocks are as follows:

Block 1. The international context

Block 2. Primary energy in Catalonia

Block 3. Final energy consumption in Catalonia

Block 4. The energy transformation sector and electricity generation

Block 5. The case of oil

Block 6. Analysis of the total, active and employed population in Catalonia

Block 7. Evolution and likely development of energy prices

Block 8. Greenhouse gas emissions resulting from energy consumption

Block 9. Examples of instruments for demand-side energy management

Block 10. Multi-scale Integrated Analysis of the Energy Metabolism of Catalonia

Block 11. Material flow analysis

Block 12. Conclusions

The period examined throughout the study is 1990 to 2005. The data employed come from the energy balance sheets for Catalonia provided by the ICAEN (2006). Data from official Spanish and European sources have also been used together with reports by international organisations. The demographic and labour data are based on the statistics and projections in Block 6 from official sources (INE, IDESCAT, etc). In order to obtain the GDP data and work out the gross value added (GVA), a homogeneous series of the Catalan GDP had to be generated from the INE's *Cuentas Regionales* (Regional Accounts) taking 2000 as the base year.

Together with this executive summary, a selection of AMEEC chapters has been published as volume 2 of CADS Reports, number 8. This includes a CD containing the whole text of the publication in pdf, this executive summary in three languages (Catalan, Spanish and English) and the data in the annexes to the different chapters in pdf and Excel format. In addition, the CD, which is also distributed separately, contains the text of those parts (AMEEC's blocks 6 and 7) not included in the paper edition.

Results

The main findings of each of the blocks are presented here below. The whole data set and detailed analyses, as well as the references to sources and reports, can be found in the main document (CADS Reports, number 8, volume 2).

1. The international context

- Primary energy consumption[1] is increasing across the world, although there are huge inequalities in the level of consumption and rate of growth. The countries belonging to the OECD are the major consumers, there are regions where consumption is rising very slowly or not at all (the former Soviet Union, Latin America and Africa) and there are others where it is rising considerably (most of the countries in Asia).

- Almost the entire increase in primary energy consumption in the world over the past 30 years concerns fossil fuels. In 2003, oil accounted for 34.5% of global primary energy consumption, coal for 24.4% and natural gas for 21.2%. The use of renewable energy and waste accounted for 10.8%, while nuclear energy represented 6.5%.

- Over the coming years, the main growth on a world scale is expected in the consumption of natural gas, followed by oil and coal. Use of nuclear energy will remain stable or increase slightly.

- The International Energy Agency (IEA) predicts that oil consumption will go up from the present 84 million barrels a day to over 121 million barrels a day by 2030. The main factor determining demand for oil is, and will continue to be, transport, which is more than 90% dependent on petroleum and its derivatives. The IEA forecasts that by 2030 the number of vehicles in the world will be almost double what it was in 2002.

- According to analysts, oil is probably very near its peak production point, known as peak oil. This means that the total amount extracted throughout the world is approaching its maximum level, following which it will start gradually to decline, even though oil will still be produced for decades after that. As demand will continue to rise, there will be a relative scarcity, which will lead to higher prices.

2. Primary energy in Catalonia

- **Between 1990 and 2005, primary energy consumption in Catalonia grew faster than GDP, which means that energy intensity (the amount of energy consumed per unit of value added) worsened**. During this period, primary energy consumption went up by 60%, from 16,702 to 26,298 ktoe. This represents an average year-on-year growth of 3%, while the average for GDP was 2.6% (figure 1).

- Oil is the main energy source in Catalonia (figure 2) and oil consumption has grown at the same rate as total energy consumption (3% per year). The consumption of natural gas is the one that has grown the fastest, quintupling in the space of 15 years as a reflection of the changes occurring in the energy generation model and in industry. Dependency on fossil fuels therefore continues and grows.

- **Fossil fuel dependency is greater in Catalonia and Spain as a whole than in other countries**. Primary energy consumption is based on oil (almost 50%) and natural gas (26% in Catalonia, 20% in Spain). Coal is also important in Spain and accounted for 14.5% of primary consumption in 2005.

- In 1990 nuclear energy was the second source of primary energy in Catalonia, accounting for 33% of the total, whereas by 2000 it had dropped to third place, accounting for 20%, although in absolute terms consumption remained relatively stable over that period. It is still the main source of electricity production, providing 56% of the total in 2005.

1. Primary energy consumption is defined as the consumption of energy contained in exhaustible natural resources (coal, oil, natural gas, etc.), or renewable resources (water, biomass, wind and solar energy, among others). It is normally expressed in tonnes of oil equivalent (toe).

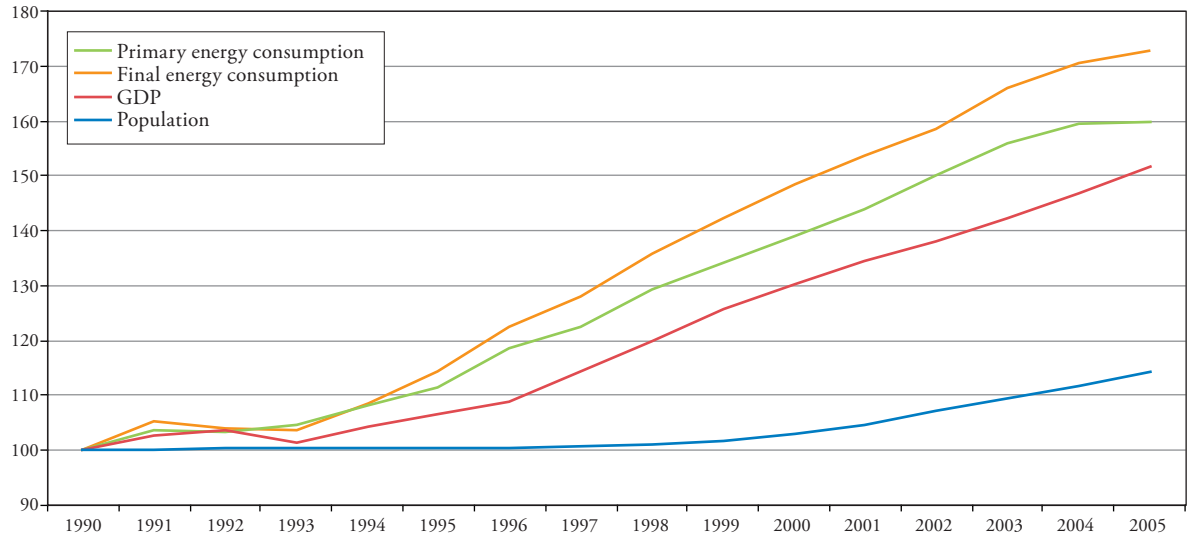

Figure 1. Growth of primary energy consumption, final energy consumption, GDP and population in Catalonia between 1990 and 2005 (1990 = 100). Source: Own calculations.

- Catalonia's nuclear power stations are expected to reach the end of their useful life within 15 to 20 years. The forecasts are that when this happens, the shortfall will be made up by natural gas. However, it should be pointed out that gas may be affected by the same sort of relative scarcity as oil in the coming decades, so that more sustainable alternatives will have to be sought.

- **The various different renewable sources account for a very small share (less than 3%) of primary energy use**. Of all the energy produced from renewable sources in 2005, half was hydraulic power; 18% came from waste incineration; 15% from woody biomass; 6% from biogas; and 6% from biofuels. Wind power produced only 3.2% of renewable energy, well below what had been forecast and what has actually been achieved in other areas of Spain. Very little use was made of solar power in terms of primary energy consumption.

- **Catalonia is a long way from achieving the targets in the Catalan Energy Plan (PEC) for the contribution of renewable energies (9% of primary energy by 2015)**. The two sources that are expected to register a big increase are biofuels and wind energy, but the year-on-year growth rates required between now and 2015 to attain the targets are extremely high: 45% for wind and 35% for biofuels.

Primary energy consumption 1990	Primary energy consumption 2005	Increase	Average year-on-year increase
16,702.1 ktoe	26,898.9 ktoe	60%	3%

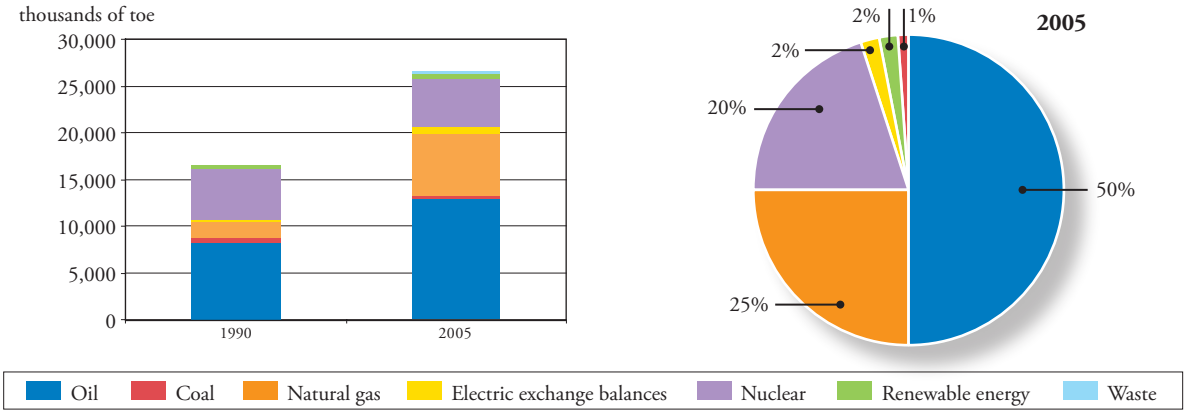

Figure 2. Primary energy consumption by energy vectors, 1990 and 2005. Source: Own calculations from ICAEN data (2006).

- The targets set by the PEC are still below the European targets (12% of primary energy from renewable sources by 2010, 20% by 2020), although these targets are expected to be met in Spain as a whole. The PEC's targets are also below European targets for renewable electricity, but above those for biofuels.

- To sum up, the Catalan energy model is still completely dependent on depletable energy sources.

A real model shift would need to involve thoroughgoing changes and a big increase in energy production from renewable sources. This must be linked to energy saving and efficiency strategies making it possible to put a stop to, and even turn round, increases in total primary energy consumption.

Primary energy consumption and final energy consumption

- Primary energy is consumed in the **energy industry** (which transforms primary energy into final energy available for consumption in the other sectors of the economy), in **non-energy uses** (the use of energy resources as raw material) and in **final energy consumption**, which is consumption in the different activities. These can be divided into transport, industry, households, services and primary sector (Figure 3).

The energy industry is the major consumer of primary energy in Catalonia. Between 1990 and 2005, there was an increase in power generation accompanied by slightly improved efficiency (less primary energy needed to generate a unit of final energy). This was due to the increased share of natural gas in electricity generation. It must be borne in mind, however, that in the long run this is not an alternative to oil, as it is also a depletable resource.

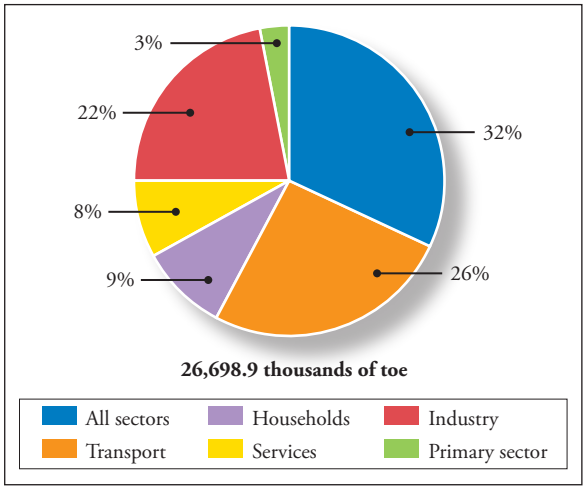

Figure 3. Primary energy consumption by sectors in 2005.
Source: Own calculations from ICAEN data (2006).

Transport is the second biggest consumer of energy. Its consumption is growing faster than the average (3.8% per year) and, in view of the huge volume involved, it is clearly the sector that sets the trend for demand. In 2005, final consumption by energy vectors was distributed as follows (see also figure 3): 98% was of oil-derived products (62% diesel oil, 21% petrol and 15% kerosene), while only 1% was electricity and 0.6% biofuels. Transport's almost total dependency on oil means it is one of the sectors in which firm action needs to be taken.

Industry has been making an effort to moderate its consumption over the past few years, which has been growing at a below-average rate (2.3% per year). In 2005, final consumption by energy vectors was 42% from natural gas (the main source of growth), 33% from electricity and 23% from petroleum derivatives.

The household sector has been growing very quickly (4.4% per year). To some extent this reflects an increase in population, but is also due to an increase in material living standards and a reduction in average household size. In 2005, final consumption by energy vectors was 43% from natural gas, 40% from electricity and 15% from petroleum derivatives, whose share is tending to diminish. Consumption of electricity and gas, on the other hand has risen a great deal. Renewables still provide a very small proportion (biomass 1.8%, solar 0.2%). The high proportion of electricity in this mix should permit the introduction of efficiency improvement measures, while more needs to be done to harness solar energy.

The services sector represents only a small fraction of total consumption, but it has the fastest rate of growth (5.75%). This is linked to the tertiarisation of the economy and the increasing energy intensity of services. Strong growth has occurred in both electricity (which accounts for 62% of final consumption) and natural gas (27%). This sector has the potential for major savings in the use of electricity and fuels for heating, the use of renewable energy (such as solar heating) and the introduction of efficient systems, such as co-generation.

The primary sector grew slower than the average (2.85%) per year). It consumes mainly oil (over 90%), almost all of it in the form of diesel oil. Although it is the sector that consumes the least amount of energy, it has a big potential for transformation, as most of its consumption is on transport.

The origin of energy and risk factors

- Catalonia is heavily dependent on external sources. Most of the primary energy consumed in Catalonia has to be imported. If nuclear energy is included (as all the uranium employed as fuel is imported[2]), the dependency rate is more than 96%. In absolute terms, imports more than doubled and continue to rise.

- This heavy dependency on energy imports could put the economy at risk. The Catalan economy is weak in the face of eventual supply problems due to shortages of crude oil, conflicts in oil-producing regions or energy price hikes that might give rise to the risk of inflation and reduce corporate competitiveness. External dependency is even more worrying in view of the fact that imports of both gas (from Algeria), and oil (from OPEC), are from a small number of countries. More than 75% of oil imports come from countries that are politically unstable or have undemocratic regimes.

- Price rises and the relative scarcity of oil will affect different sectors of the economy in different ways. The use of oil is likely to be prioritised in activities to which it contributes greater value added and for which, for the time being, it is irreplaceable, such as the chemical industry and its subsectors. This will make it necessary to find alternatives for the other industries and sectors.

- One of the solutions being put forward in the transport sphere is the use of biofuels. If the raw material has to be imported in any case, then it is better to diversify the origin of the primary energy employed. However, this does not get over the problem of external dependency on energy sources (apart from other impacts on the exporting countries).

- In the case of natural gas, the state of the infrastructures is also an important consideration, as is the need to diversify imports by means of gas pipelines and gas tankers (in the form of liquefied natural gas). The problems associated with natural gas are similar to those associated with oil, as practically all of it has to be imported, the trend is for prices go up and it is a depletable resource.

- The increased use of natural gas for power generation (combined cycles and co-generation) means that the security of the electricity supply depends on the availability of gas infrastructures to deliver fuel.

- Coal is used very little in Catalonia and most of it is imported. Attention will have to be paid to the performance of the new coal technologies, which are more efficient and produce lower emission levels, and wind technologies, which are not developing as expected.

- Indigenous primary energy is generated mainly from renewable sources, which have the advantage of being local and spread throughout the territory. Nevertheless, increased use of such energy depends on generation costs falling in relation to other sources, and the incentive policies that are put in place. Catalonia has a big potential for solar and wind energy, but so far neither has been developed as originally predicted.

The case of biofuel

- Analysis of the consequences of a possible expansion of the use of biodiesel in Catalonia shows that biofuels are not an adequate solution on a large scale. To comply with the targets in the PEC (for 12% of transport energy to come from biodiesel by 2015) most of the raw material would have to come from new plantings which, if they were in Catalonia, would take up 131% of its agricultural land or 38% of the country's entire territory. This means that part of the biofuel will have to be produced from imported raw materials. Growing such raw materials has repercussions in terms of water consumption and the use of fertilisers, as well as the fact that it replaces food crops.

- Biodiesel combustion produces more nitrogen oxide emissions than ordinary diesel (and a lot more than petrol), although it emits smaller amounts of other pollutants. This needs to be taken into account when considering the promotion of biodiesel in Catalonia, as the high NO_x levels associated with transport are a serious problem for air quality in the Barcelona metropolitan area.

- The expansion of crops to provide biofuels for European countries is a source of great concern due to its impact on the food security of developing countries, changing over from food crops to energy crops for export.

- The findings suggest it would be better not to incentivate the large-scale use of biofuels, but rather take steps to save fuel in transport. It would be necessary to continue to encourage advantage to be taken of

2. Nevertheless, official statistics generally treat nuclear energy as being produced domestically.

used oils and other waste for the production of biodiesel in Catalonia.

3. Final energy consumption

- Final energy consumption in Catalonia has been growing faster than GDP in real terms. The biggest relative increases have been in the services sector, households and transport, the last of which has experienced the biggest growth in absolute terms and is the leading consumer sector.

- Final energy consumption in Catalonia has been dominated by petroleum-derived products (51.6%), electricity (24.3%) and natural gas (22.8%), which registered the biggest increase (150%). Figure 4

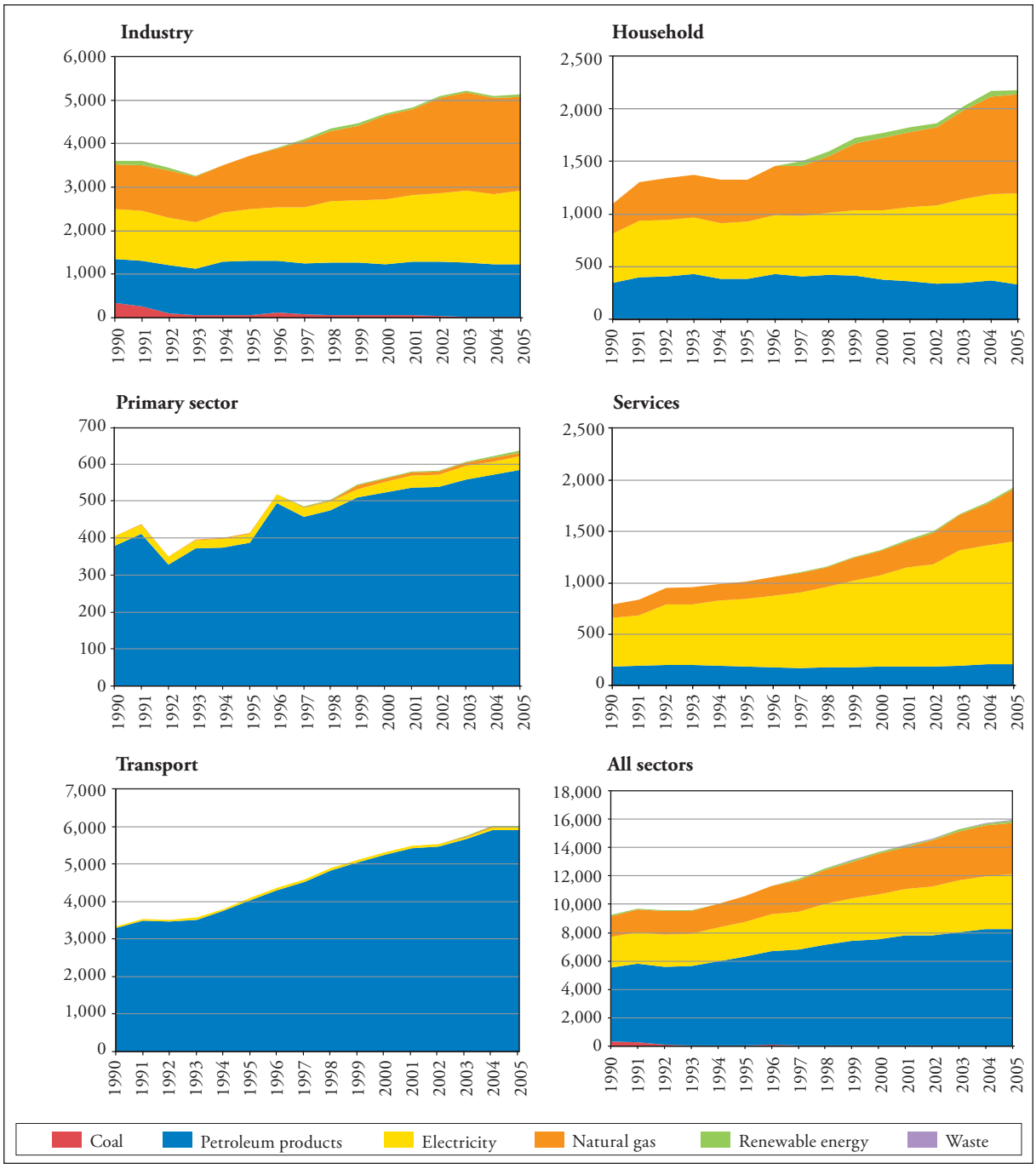

Figure 4. Final energy consumption in the different sectors in the period 1990-2005 (in thousands of toe).
Source: Own calculations on the basis of ICAEN data (2006).

	1990		2005		Increase in absolute terms	% increase over total increase
	ktoe	% of total	ktoe	% of total		
Primary	405.3	4.4	635.6	4.0	230.3	3.4
Industry	3,605.9	39.1	5,178.2	32.5	1,572.3	23.4
Services	788.4	8.5	1,930.0	12.1	1,141.6	17.0
Transport	3,329.1	36.1	6,018.4	37.7	2,689.3	40.1
Household	1,099.9	11.9	2,180.7	13.7	1,080.8	16.1
Total	**9,228.6**	**100**	**15,943.0**	**100**	**6,714.4**	**100**

Table 1. Final energy consumption by sectors. Absolute values, relative share and increases in Catalonia between 1990 and 2005.
Source: Own calculations on the basis of the energy balances supplied by the ICAEN.

shows the contribution of each of the energy vectors to the different economic sectors in the period 1990-2005.

- A methodology has been applied to this block which has enabled the amount (and composition) of primary energy entailed by a given level of final energy consumption by the different sectors and activities to be calculated.

- One of the main results of this exercise is the finding that the amount of primary energy employed to produce one unit of electricity fell slightly (from an average of 2.96 in 1990-1992 to 2.59 in 2003-2005). In addition, the average composition of the primary energy sources used to generate a unit of electricity changed. Whereas at the beginning of the period 2.41 units of nuclear primary energy went into generating one unit of electricity, by the end of the period only 1.56 such units were required. In contrast, the average amount of natural gas needed rose from 0.12 to 0.65 units.

- The factorial breakdown makes it possible to explain the causes of the total changes in primary energy needs in the Catalan economy on the basis of a breakdown into three factors: the changes in the level of final consumption by different sectors (the "activity effect"), the shifts between different types of final energy (the "substitution effect") and the changes in primary energy needs for obtaining final energy (the "transformation effect").

- **The activity effect** is by far and away the most important of the three for all activities. It leads to an increase in the requirements of all sources, particularly oil, because of transport, and as a result of growing demand for petroleum-derivates for non-energy uses.

- **The transformation effect** reduces primary energy needs and is strongest in the demand sectors most dependent on electricity.

- **The substitution effect** explains the variations in the requirements for certain primary energy sources, but is not at all a factor in explaining the changes in total primary energy in the period analysed.

- The primary energy requirements registering the biggest growth were those for natural gas, for both electricity generation and final consumption in industry, services and households. Use of nuclear energy increased very little in absolute terms, while coal was the only source consumption of which actually fell.

- It should be pointed out that in the period 2003-2005 there was heavy dependency on imports of already refined petroleum-derived products, whereas, in terms of energy units, in the period 1990-92 exports of such derivatives exceeded imports.

4. Energy transformation and electricity generation

- Electricity consumption in Catalonia has grown significantly, rising by 79% between 1990 and 2005.

- There has been little diversification of the energy sources used for generating electricity in Catalonia. According to data from 2003, nuclear energy contributed the biggest share (56% of the electricity consumed). The next most frequent source was natural gas (25%), 9% of which was consumed in combined-cycle thermal power plants and the rest in co-generation. The coal-fired power station in

Cercs provided little more than 1% of electricity in 2003 and the fuel oil-fired power plants only 3%. The other energy sources employed were hydroelectric (13.3%), waste incineration (0.7%), wind farms (0.4%) and biogas (0.2%).

- All the power stations operating in the so-called *special regime* (i.e. those making use of renewable sources, except hydroelectric ones, and other ways of producing power regarded as efficient, such as co-generation) generated about 20% of the gross electric energy produced, 14.5% in co-generation.

- In 2003, nuclear power plants represented only 31% of the total installed power, which means that they operate more intensely than other power plants. Special regime power stations accounted for 17% of installed power, while the coal- and fuel oil-fired power stations represented 14% of the total.

- The contribution of renewable energy is very low. In 2003 they generated only 14.5% of the electricity produced, with 11% coming from the big hydroelectric power stations. Hydroelectric power is subject to big variations depending on the amount of available water in the reservoirs, which means that the model is not very diversified and is exposed to periods of low output. In 2004, renewable energy was responsible for 19.2% of gross electricity generation in Spain as a whole.

- The Catalan electricity generation model needs major changes and improvements in the most immediate future for the following reasons: a) heavy external dependency; b) little diversification of resources; c) high output of radioactive waste and CO_2 emissions; d) strong centralisation in a small number of power stations and a polarised grid with losses in the transport of electricity.

- The presence of three nuclear power plants in Catalonia implies a risk and a series of problems related to nuclear waste. These power stations are due to be closed during the decade beginning in 2020. A gradual closure calendar is required so that work can be done on replacing them with more sustainable alternatives.

- The IER[3] Scenario in the Catalan Energy Plan forecasts a 57% increase in demand for electricity between 2003 and 2015. Limiting this strong growth in electricity demand is one of the biggest challenges facing us in the coming years and conditions the possibility of transforming the present model. Efforts will need to be stepped up to improve efficiency and savings in final energy use.

- In order to generate the necessary electricity, it is planned to keep nuclear-generated output at the same level in absolute terms until 2015 (while it declines in relative terms to 35.3% of the total by that date) and increase the capacity of the combined-cycle power stations by 2,000 MW of installed power. The plans for the only coal-fired power station left in Catalonia and one or two of the fuel gas- and diesel oil-fired thermal power stations are to stop operating. The contribution of fossils fuels and nuclear energy combined will be more than 76%.

- The forecast is that the proportion of wind-generated energy will increase. On the Intensive Renewable Energy Scenario (IER) it will supply 12.11% of the total with 3,500 MW installed power by 2015. In 2006 there were 11 wind farms in operation with 225 MW of installed power. The other renewable energy technologies (woody and agricultural biomass, photovoltaic production and waste reduction) are growing very fast, but still contribute very little to power generation.

- The forecast regarding renewable energy in the Energy Plan of Catalonia (PEC) means that Catalonia will not reach the target of 29.4% by 2010 set by the State for Spain as a whole. According to the Plan's Intensive Renewable Energy Scenario, the contribution of renewables will reach 23.5% by 2015.

- The electric energy transport system in Catalonia consists of two main grids supplying energy from the big production centres (the nuclear power stations, the hydroelectric power stations in the Pyrenees) to the areas of greatest consumption (Barcelona). However, transporting electricity leads to some of it being lost (8.5% of the electricity generated, according to the PEC), so steps must be taken to bring the places where electricity is generated closer to where it is consumed (distributed generation).

- The special regime facilities often operate on the distributed generation model. There is a need to promote co-generation and distributed networks, as they are more efficient systems, and to incorporate renewable energy sources. The infrastructure of a distributed generation grid would enable the gap left by the closure of the nuclear power stations to be filled by cleaner and more efficient technologies.

3. Intensive Renewable Energy Scenario.

In regard to **natural gas**, the following remarks are in order:

– At the present time the natural gas grid is expanding so that most of the Catalan population will have access to natural gas by 2015. This will therefore mean an increase in household gas consumption.

– All the combined-cycle and many of the co-generation power stations are fired by natural gas. It will therefore be necessary to ensure the supply of natural gas in order to guarantee the electricity supply.

– It will also be necessary to ensure maintenance of the natural gas storage and distribution infrastructures in Catalonia to be able to cope with external problems.

• In conclusion, over the next few years Catalonia is faced with the challenge of taking the first steps towards making significant changes in its electricity generation model and also laying the groundwork enabling effective transformation of the model to be carried out in the medium term.

• In the short term it will be necessary to increase the use made of renewable energy and improve the efficiency of the electric power generating systems. In the medium term, preparations will have to be made for the gradual abandonment of nuclear energy and putting in place new techniques and facilities for harnessing renewable energy sources and more efficient generation and distribution systems.

• It is extremely important to promote research and development in new generation technologies using renewable energy, and to carry out projects incorporating innovative technologies. This ought to include, in the short term, the carrying out of pilot schemes, such as the installation of solar thermoelectric power stations and co-generation plants for supplying newly built-up residential, commercial and industrial areas.

5. The case of oil

Oil is the most used energy resource in Catalonia, accounting for almost 50% of primary energy, and is extremely important for the functioning of the Catalan economy. That is why a specific block has been devoted to it focusing on its two main uses: transport and non-energy uses.

• In view of the scarcity of their oil reserves, Spain and Catalonia are heavily dependent on oil imports. Three of the four oilfields in Spain are in Catalonia, off the coast of Tarragona. However the volume of oil they yield is very small. In spite of the fact that oil prospecting permits have recently been granted in Catalonia, the situation is not expected to change.

• Most imports (figure 5) come from North Africa and the Middle East, and it is precisely these regions that will provide the biggest share of exports on the global market in the future. Spain's and Catalonia's current dependency on imports from these areas will therefore increase.

• Oil consumption in Catalonia is divided up as follows (data for 2005: figure 6): 25% for non-energy uses, 12% for the energy sector (of which less than 2% is used for generating electricity, the rest being consumed by the refineries), 45% for final consumption in transport, 9% for industry and the remaining 9% for all the other sectors combined (household, services and primary).

• The refineries sector in Catalonia is quite big. Nevertheless, there is a shortage of diesel oil refining capacity, which means that diesel oil has to be imported, whereas a small proportion of the petrol produced in Catalonia is exported.

Looking specifically at **non-energy uses** and **transport** we find:

• The consumption in Catalonia of petroleum-derived products for **non-energy uses** has almost doubled in the 15 years that have been analysed. The most important of these products are naphtha and liquid petroleum gases, which are used in the olefin plants and one propane dehydrogenation plant in the Tarragona petrochemical complex.

• This is a use of oil that cannot be replaced by any other substance in the short term if this industry is to be maintained and it is one of the uses contributing the most value added to the economy. It should be noted that the Catalan chemical and petrochemical industry is an important part of Catalonia's industrial fabric.

• As much as 98% of the fuels used in **transport** are petroleum derivatives and the data indicate that transport is responsible for almost half the oil consumed in Catalonia and more than a third of all final energy consumption (37.7% in 2005). Moreover, consumption by transport is rising very rapidly (by 3.7% a year) and so this is a key sector on which it is necessary to act in order to reduce the demand for oil.

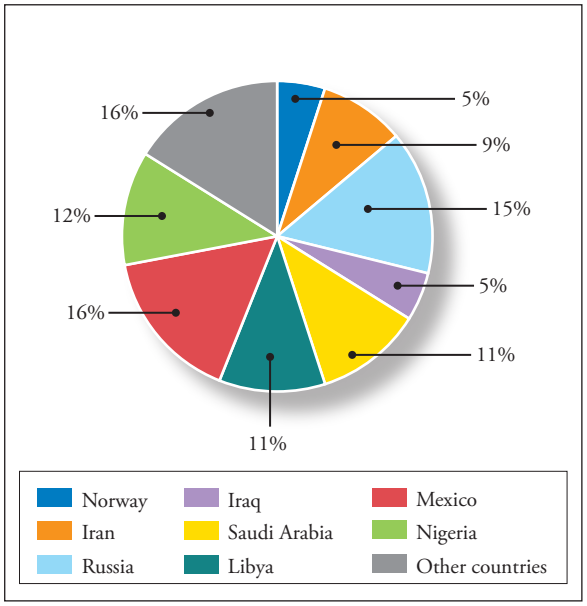

Figure 5. Spain's oil imports by country of origin (2005).
Source: CORES, 2006.

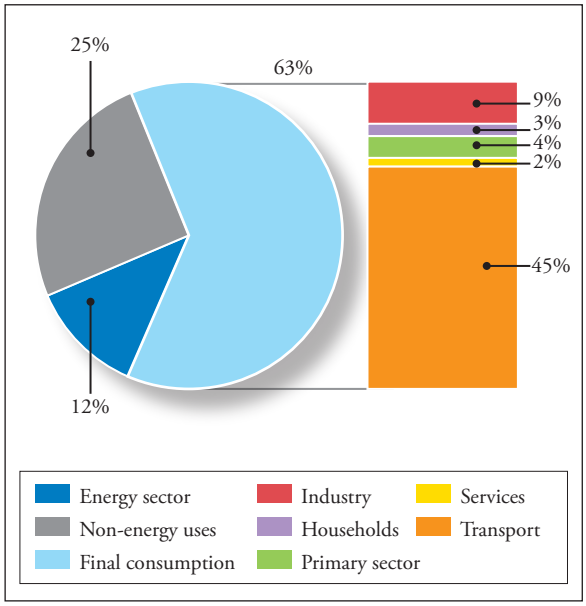

Figure 6. Consumption of oil-derived products by sector, 2005.
Source: Own calculations on the basis of ICAEN data (2006).

- Road transport is the mode with the highest consumption (83%), half of which occurs in urban areas. Private cars account for 42% of total energy consumption, vans for 31% and lorries 23%. Consumption by public transport in the towns and cities represents just 2% of the total.

- It has been calculated that the energy consumed by transport is shared equally among goods and passenger transport. There are many different factors explaining increased energy consumption by transport:

– As far as goods transport is concerned, it is important to highlight, on the one hand, Catalonia's geographical situation, bordering on France in the north and with a coastal strip with two major ports in Barcelona and Tarragona. On the other hand, the Catalan economy has a high volume of imports from and exports to the rest of Spain and all over the world. Moreover, many of these goods reach Catalonia by rail or sea, but continue their journey by road, so that 76% of all goods transport is by road and only 3% by rail. This stands in contrast to the EU-15 average, which in 2002 was 12.9% (tending to plateau out in absolute terms, which means that the growth in goods transport is by road), and to the average in the United States, which was 43.1% in 2001.

– As far as passenger transport is concerned, the population's increased mobility needs are being met mainly by private vehicles. This is due to the country's territorial configuration, with a lot of scattered population nuclei, and the inadequacy of public transport in many areas. Indeed, over the past few years there has been a big increase in forced mobility (linked to work or study, up by 2.3% a year since 2001) and unforced mobility (leisure), concerning mainly mobility between different municipalities. Private transport now accounts for 70% of these journeys. Another contributing factor is the growing number of vehicles on the roads (up by 68% between 1995 and 2005).

- Efforts therefore have to be made to reduce fuel consumption in transport by improving vehicle efficiency, using more efficient fuels, shifts in transport modes, fostering greater use of rail for goods transport, and public transport in general for passenger transport, and prioritising investment in public transport over spending on roads. Work also needs to be done to reduce mobility needs through town and regional planning.

6. The total, active and employed population in Catalonia

- The population of Catalonia grew from just over 6 million inhabitants in 1990 to nearly 7 million by the end of 2005. This growth occurred mainly in the latter part of this period, from 1999 onwards.

- The Catalan population is forecast to grow by around 500,000 people between 2005 and 2010, and by a further 300,000 between 2010 and 2015. The increase will be principally in the under-16 and over-64 age groups. Therefore the dependency ratio (the ratio of the economically inactive population to the active population) will increase.

- Catalonia's economically active population is set to grow especially in the next four years, during which time it will go up from 3.6 million to 3.9 million by 2010. By 2015, the economically active population will be around 4 million. This growth in the economically active population will occur almost entirely in the 45-64 age group. The activity rate for women is expected to rise and approach that for men. Moreover, people's active lives will be longer and the average retirement age will therefore go up.

- On the basis of this active population, if the employment rate of the past two years (around 92%) is maintained, the employed population will increase by 280,000 between 2005 and 2015.

- The forecast is that this growth will occur especially in the services subsectors associated with growth in the young and old segments of the population (public administration, education, health, social services and domestic services). These subsectors are highly labour intensive and are expected to provide work for about a fifth of those in employment by 2015.

7. Evolution and likely development of energy prices

- World oil prices fluctuate a great deal, often as a result of factors related to political stability. They are also influenced by increased demand when this is not matched by increased output.

- Over the next few years demand for oil and other energy sources is expected to increase due to the strong economic growth forecast, especially in countries such as China and India. This, coupled with scant investment in increasing the capacity for extracting and refining oil, will continue to produce further price rises in the future.

- Oil prices rose steadily and steeply from 2002 to the summer of 2006 (when they reached 78 dollars a barrel). The average price in May 2007, when this study was concluded, was 67.92 dollars a barrel[4], but by 10 March 2008 the West Texas Intermediate crude oil price had shot up to 107.56 dollars a barrel[5].

- It is not only oil, but all the other fossil fuels, as well as uranium, which are affected by these price rises. Indeed, a comparison of the evolution of oil and natural gas prices shows that both these fuels follow similar paths, although it is oil that sets the trend.

- Final energy prices in Catalonia – the prices paid by consumers – are lower than those in most other European countries, in spite of a slight upward trend. This can be seen in the prices of petrol and diesel oil, liquefied petroleum gas, fuel oil and natural gas. The average price of electricity in Catalonia is also below the EU-15 average and has even gone down in real terms over the past 20 years. It should be pointed out, however, that the price structure means that this average conceals a wide range of very different situations, depending on whether the final consumer is a company, a government department or an ordinary member of the public.

Factors affecting the evolution of prices

- The medium- and long-term evolution of energy prices is influenced by many factors, including the evolution of proven reserves, forecasts of increased energy demand, the capacity for refining energy products, etc.

- Both the International Energy Agency (2006) and the United States Department of Energy (Energy Information Administration, 2006) forecast an increase in primary energy demand in all regions due to annual economic growth of between 1.6% and 2% up to 2030. Some 75% of this increase will come from countries outside the OECD.

- This increased demand will have to be covered by increased output (which will accelerate the depletion of reserves) that will have to come from the OPEC countries. It is estimated that these countries' output will have to go up from 30-32 to 70 million barrels per day (mbd) by 2030. The other oil-producing countries do not have the capacity to raise their output.

4. According to www.oilnergy.com. Last visit, 12 June 2007.

5. According to www.bloomberg.com/energy. Last visit, 10 March 2008.

- The quality of the world's oil reserves is deteriorating and more and more energy is required to extract the energy we need. The energy return on investment (EROI) for oil is currently only 11[6] (Cleveland, 2005), whereas in the 1930s in the United States it was 100.

- There are different estimates of existing oil reserves. According to the EIA (2006), oil reserves in 2006 stood at 1.3 trillion barrels, 71% of them in the Middle East. A more conservative estimate (Campbell, 2002) put oil reserves at 884 billion barrels and forecast that peak oil, with an output of 31 billion barrels a year, equivalent to 85 mbd, would be reached by 2010.

- Huge investments are needed to increase output capacity to meet world energy demand, which the International Energy Agency (2003) put at 16 trillion dollars up to 2030. However, there is no guarantee that these investments will be made, nor, if they are, when they will be made or whether they will be in the countries where they are needed (in the case of oil, mainly those in the Persian Gulf).

The impact of price rises on the economy

- A sudden jump in the price of oil means a loss of competitiveness for oil-importing economies. It requires an adjustment to wages and export prices to ensure that the level of activity does not go down too much. It produces a relative impoverishment of the population.

- The drop in economic activity due to the loss of competitiveness and purchasing power by the population may be even bigger if most of the country's trading partners are net oil importers. This is the position Catalonia is in, as in 2005, 74% of its exports went to countries in the European Union.

- The effect of increased oil prices depends on various factors, such as the proportion of national income required to foot the oil bill, the degree of dependency, the ability of consumers to change over to other energy sources, etc. Studies have been carried out in regard to Europe and the United States which agree in forecasting a rise in inflation and a fall in GDP growth rate.

Geopolitical risks and energy strategy

- The majority of the world's hydrocarbon reserves are in the Middle East and the former Soviet countries, in the hands of state-owned companies. Commercial contracts often have more to do with these countries' bilateral policies with the purchasers than with market considerations[7].

- Around 75% of oil imports by Catalonia and Spain in 2004 came from undemocratic or unstable countries: 50% from six OPEC members (Saudi Arabia, Libya, Nigeria, Iran, Iraq and Algeria) and 15% from Russia. The situation with regard to natural gas is even more worrying, as in 2004, 51% came from a single country, Algeria, 17.4% from Nigeria and 14% from Qatar. In 2005, gas imports from Algeria went down to 43%.

- This means that both Catalonia and Spain run a high political risk due to their energy dependency, so that what happens in the Maghreb and the Middle East is of special importance for the Catalan economy.

- A precaution-based strategy needs to envisage various oil price scenarios indicating how the economy might react. Even so, we know that prices will continue to rise and therefore that there will be negative impacts.

- From a purely economic point of view, the best strategy would be to reduce the economy's dependency on fossil fuels, which would also have other benefits for the environment and international stability.

8. Greenhouse gas emissions due to energy consumption

- CO_2 emissions due to energy consumption in Catalonia rose sharply in the period under consideration – by 60.1% –, much more than the average for Spain as a whole (50.5%).

- The increases in population and the availability of goods and services per capita are not sufficient to explain this increase in total emissions. Per capita emissions went up by 44.9%, while GDP went up by 33.4% and the population by 10.5%. Therefore, other explanatory variables need to be found.

6. 11 units of energy are obtained for every unit of energy used in extracting oil.

7. For example, the loans China made to Russia for it to nationalise Yukos, Russia's cutting of the gas supply to the Ukraine in 2005 and the way China has protected Iran in the United Nations Security Council.

- The increase in GDP's emissions intensity (tonnes of CO_2 per million euros of GDP), which was 8.66%, can be explained in large part by the increased energy intensity (consumption of primary energy per unit of GDP, which grew by 8.36%).

- The carbonisation index (CO_2 emissions per unit of primary energy consumed) was the same at the beginning and end of the period. None the less, the fluctuations in this index do explain the reduction in emissions per unit of GDP that occurred between 1995 and 1998, and the big increase over the past few years. The carbonisation index depends on the mix of energy sources used and the energy efficiency in their transformation.

- The transport sector is the one that contributed most to the increase in CO_2 emissions, where they rose by 31.6%. Road transport makes intensive use of energy and is fed by the consumption of fossil fuels, so it pushes up energy intensity and carbonisation index, thereby offsetting the changes in other sectors (such as industry), where such fuels have been replaced by others that emit less CO_2.

- Industry is responsible for 16.9% of the increase in CO_2 emissions. However, in terms of final energy consumption, growth was higher, at 17.3% of the total. This was made possible by fuel substitution (reduced consumption of carbon and petroleum derivatives; and greater use of natural gas, which produces less CO_2 emissions per TOE). Nevertheless, the amount of electricity consumed by industry went up considerably, which leads to higher emission levels (via the transformation effect).

- The service and household sectors have evolved in very similar ways. In both of them, consumption of oil products has slowed down, while consumption of natural gas has increased substantially. There has also been a big increase in electricity consumption (up by 123.4% in the service sector and by 61.3% in the household sector), accompanied by increases of 9.3% and 8.6%, respectively, in emissions.

- A comparison of the percentage increases caused by the different process effects (carbonisation, transformation, substitution and final energy consumption) on emissions and necessary primary energy shows that the most important factor is the increase in final energy consumption.

- Replacing certain fuels by others – mainly natural gas – has helped to diminish emissions, but only by a very small amount which is not enough to make up for the increase in primary energy needs. Source substitution has had a much more significant impact on reducing emissions than on diminishing primary energy needs.

- Although there has been a certain decarbonisation, the transformation effect (shifts in the energy sector's sources and efficiency) has had a negative effect as far as CO_2 is concerned and has helped to increase emissions by 14%, although, as far as primary energy is concerned, transformation needs fell. The main reason for this is the decreasing share of electricity produced by nuclear energy as against that generated by natural gas-fired power stations. The latter are more efficient at converting heat into electricity, but emit CO_2. This is an example of the different conclusions that can sometimes be drawn from an analysis in terms of primary energy or carbon emissions. Possible improvements in on-site carbon capture technology in the electric power stations may well affect the carbonisation index.

- In conclusion, both total emissions and emission intensity per unit of GDP increased a great deal over the course of the period under consideration, so Catalonia is still a long way from meeting the Kyoto Protocol commitments. Policies need to be implemented aimed at improving energy efficiency and reducing emissions per unit of energy if Catalonia wants to stop its economic growth from continuing to bring with it greater emissions (in both absolute terms and per unit of GDP).

9. Examples of instruments for demand-side energy management

There follows a broad spectrum of energy management measures, although this is not meant to be an exhaustive list of proposals.

Energy management instruments

- Although government grants are used to encourage the installation of energy-saving and energy-efficient measures and to promote renewable energies, other energy management measures such as the following can also be implemented:

– **Economic incentives** to reduce energy demand, such as the "50-50 concept" with regard to equipment (50% of the money saved by reducing consumption goes to the user, while the other 50% goes

to the managing organisation) and the recycling of energy investments (setting up a capital fund for efficiency measures drawing its resources from the amounts saved by the measures in question).

– **Energy agencies and companies**, public-sector or mixed public- and private-sector, making it possible to set up an institutional structure to promote and implement energy saving, energy efficiency, renewable energy sources and distributed generation.

– **Least cost planning** consists in the introduction of demand control measures among those to be considered in energy planning.

– Different tiers of government can act as an example through **public-sector purchases** that take into account energy-saving and efficiency (in regard to equipment, by including efficiency criteria in the conditions for works, services, public buildings, etc.).

– Shifting the marketing model towards **energy services** (i.e., heating, air conditioning, lighting, the power of electrical appliances) means that it is the company providing the services (and the owner of the installations) that has the biggest incentive to supply the contracted services with the minimum expenditure of energy.

Taxation in the energy sphere

• The use of taxation to provide incentives for behaviour with less environmental impact is an energy policy instrument that has so far been little explored. It can be applied to consumers, energy-consuming activities and the energy sector.

• Existing taxes in Spain on the sale of hydrocarbons and electricity were not created for the purpose of reducing energy demand. Reforming these taxes would enable them to achieve better results in environmental terms. Catalonia has certain powers to legislate in regard to centrally regulated taxes. The three most important possibilities in regard to energy taxation are:

– Deductions for investment in renewable energy on the full share of personal income tax payable to the Autonomous Community.

– An increase in the special tax on certain means of transport within the legally permitted limits.

– The introduction of a rate payable to the Autonomous Community on the levy on retail sales of certain hydrocarbons (i.e. an increase in the current "health cent", a tax on petrol allocated in full to health expenditure).

• The Autonomous Communities can also create taxes of their own affecting energy use (within the limits of state-wide Spanish legislation), although Catalonia has not yet done so. Measures along these lines have been taken in Galicia, Castile-La Mancha, Andalusia, Aragon, Murcia and Extremadura, such as taxes on SO_x and NO_x emissions (which affect power stations, refineries and major energy consumers), electricity generation in nuclear power plants and the storage of nuclear waste.

• At the international level, one of the most interesting cases is the British Climate Change Levy, a state tax on energy use in industry, commerce and the public to encourage users to improve energy efficiency and reduce emissions of greenhouse gases.

• Local authorities can also apply fiscal measures to reduce energy consumption, in particular within the current legislative framework of the Property Tax (IBI), the Business (IAE), the Tax on Mechanical Traction Vehicles, the Buildings, Installations and Works Tax, and certain rates.

• Energy taxation can play an important part within an integral approach to ecological tax reform. This is usually associated with an increase in environmental taxes parallel to a reduction in other taxes, in particular employers' Social Security contributions, which are levied on – and therefore act as a disincentive to – the labour factor. This would lead to what is known as a double dividend, that is to say, benefits in the environmental and economic, particularly labour, spheres.

Emission quotas and energy consumption

• Tradable Emission Quotas (TEQs) are another type of measure, which seeks to generate changes in the behaviour of individuals and organisations leading to reduced energy consumption and CO_2 emissions.

• TEQs are an instrument for regulating energy demand based on the allocation of equitable emission rights that can be exchanged. Every citizen periodically receives a certain quantity of emissions rights free of charge, while organisations (governments, companies, etc.) buy the rights they need at auction or through brokers. The volume of rights diminishes over time according to previously established global emission reduction targets.

• TEQs are regarded as an instrument that is fair (every adult initially has the same number of rights), en-

vironmentally effective (it indirectly covers all energy uses) and potentially efficient in the medium- and long-term. It explicitly introduces the notion of co-responsibility and gets citizens and economic organisations directly involved in promoting change in the energy model. It must be borne in mind that it may also have negative socio-economic effects.

- It is an instrument that has still not been put into practice, although it is generating a great deal of political and media debate in the United Kingdom, which is where it originated. Before being implemented, its viability must be analysed from the administrative, economic and technological standpoints, as well as in terms of how it would be perceived by civil society.

In conclusion, there exist a large number of economic and fiscal measures for promoting changes in energy demand, many of which have already been implemented in other places. In Catalonia, it would be necessary to begin putting into practice economic and fiscal measures within the scope of the Catalan autonomous government's powers as well as prevailing upon other tiers of government to do so too.

10. Multi-scale Integrated Analysis of the Energy Metabolism of Catalonia

This block presents the analysis of the energy metabolism of the Catalan economy for the period 1990-2005, using the MSIASM (Multi-Scale Integrated Analysis of Societal Metabolism) methodology, which enables economic processes to be examined from an energy point of view.

- This approach is based on an accounting of the energy used in different components of the economic system. This information is combined with economic, demographic and labour market data.
- Such analyses have already been performed on various different economic systems, thus allowing comparisons to be made with other countries belonging to the same geographical and economic area as Catalonia.

Societal metabolism: All economic processes involve the transformation of energy and materials to produce goods and services, in an analogous way to how an organism metabolises food and turns it into physical work. One repercussion of this is that the waste generated and the heat given off end up in the environment. Economic activity can therefore be described in biophysical terms as a function of the amount and type of energy and materials used. When analysing the particular case of the energy vector, the term ***energy metabolism*** is used.

- In the MSIASM, the Catalan economy is divided into two major sectors: the paid work (PW) sector, which generates value added, and the non-productive, or household (HH) sector, which includes the dependent population, unpaid work and the time the active population does not devote to work. At the same time, the paid work sector can be further divided into three subsectors: the productive sector (PS), services and government (SG) and the primary sector, or agriculture (AG).

Three main variables were used in the analysis:

– The amount of energy consumed, or energy throughput (ET), in total (TET) and in each sector.

– The time society dedicates to each human activity (HA), which is calculated on the basis of the population, the active population and the number of hours worked.

Indicator	Definition	How calculated	What it measures
EI_i	Energy Intensity [MJ/€]	= TET/PIB	The amount of energy consumed per unit of GDP.
EMR_i	Exosomatic metabolic rate [MJ/h]	= ET_i/HA_i	The amount of energy consumed per hour allocated to the sector i.
ELP_i	Economic labour productivity [€/h]	= PIB_i/HA_i	The amount of added value generated by one hour of working time in activity i.
ELP/EMR_i	Energy efficiency of productive activities [€/GJ]	= PIB_i/ET_i	The economic efficiency with which energy is used.

Table 2. Definition of MSIASM indicators.

– The GDP, or Gross Value Added, of each economic sector.

On the basis of these variables (which can be applied to the economy as a whole, to each sector or to each subsector) four indicators were calculated for the MSI-ASM (table 2).

Results of the MSIASM

- In economic terms Catalonia experienced strong growth between 1990 and 2005, with a yearly growth rate of 2.64%. In 2005, per capita GDP was just over € 21,000 per inhabitant, similar to the EU-15 average.

- The different sectors' shares in the **generation of Gross Value Added** were extremely uneven. Services contributed 64% of GDP, industry 34.4% (including 8.4% by construction) and agriculture just 1.6%. These percentages closely match the proportion of activity time allocated to each sector.

- The number of **hours of activity** is distributed very unevenly among the three subsectors. What is more, it may be said that there has been a change in the structure of the active population. In 2005 the leading sector was services (63.4%) and was continuing to grow. Industry's share fell from 43.7% in 1990 to 34.2%. Agriculture continued to decline and by 2005 accounted for only 2.4% of all the hours allocated to productive activities.

- Per capita **primary energy consumption** reached 160 GJ in 2005, showing a strong tendency to converge with the European average (167 GJ in 2004). This means that the economic structure and household consumption are approaching European levels.

- Catalonia's **energy intensity** (EI) increased during the period (figure 7), bringing it up nearly to the EU-15 average (7.9 MJ/€ el 2004). The countries belonging to the same geographical and economic area as Catalonia have similar data, but are tending to reduce their energy intensity and gain in efficiency (as is happening in Germany, the United Kingdom and the EU-15).

- A breakdown by sectors shows that energy intensity is most pronounced in industry and this is therefore the sector needing most energy for each euro of value added it produces, with the primary sector not far behind (see table 3). The sector requiring the least energy is services, but in all three cases the trend is towards a modest increase in energy intensity.

- **Economic labour productivity** (ELP) in the services sector is slightly higher than in industry. In both cases it was between €20 and €25 per hour worked throughout the whole period and declining in the most recent years. It was much lower in the primary sector: €10-15 per hour. Overall, economic labour productivity did not grow, which means that the economy became less competitive. This is all the more serious as energy intensity increased in all sectors.

- Society's average **exosomatic metabolic rate** (EMR_{SA}), i.e. the amount of energy consumed per hour by Catalan society, went up from 13.1 MJ/h in 1990 to 18.4 MJ/h in 2005. Most energy is con-

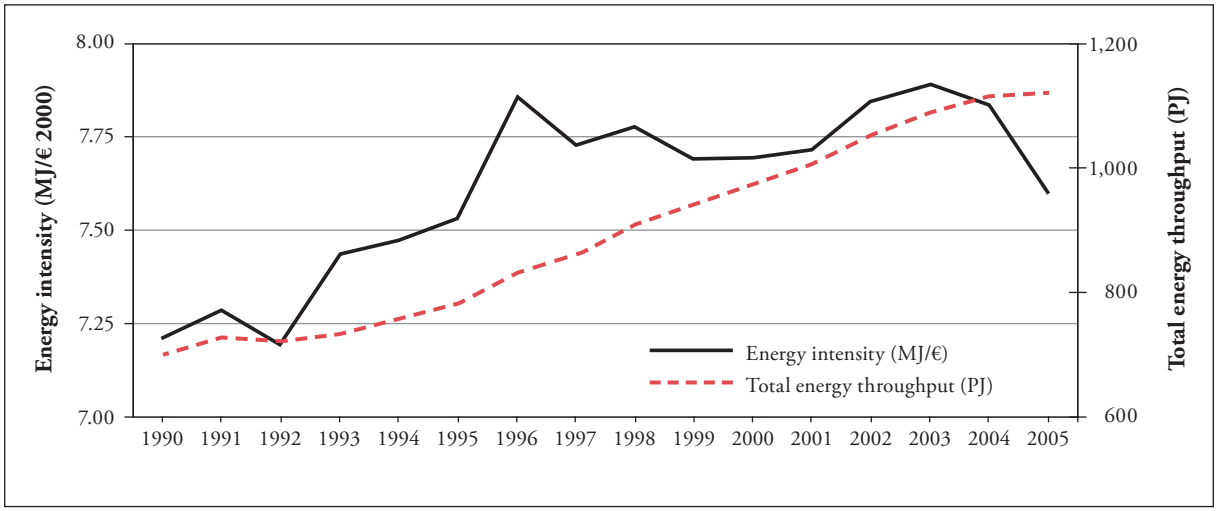

Figure 7. Evolution of energy intensity (EI) and total energy throughput (TET) in Catalonia (1990-2005).
Source: Own calculations from ICAEN (2006) and INE data.

	EMR	EI	ELP	ELP/EMR
Total Catalonia	**18.4 MJ/h**			
Production sectors	**167.3 MJ/h**	**7.6 MJ/€**	**25.54 €/h**	**152.6 €/GJ**
Primary	178.2 MJ/h	13.6 MJ/€	13.1 €/h	73.7 €/GJ
Industry	331.1 MJ/h	15.7 MJ/€	21.0 €/h	63.5 €/GJ
Services	75.1 MJ/h	3.4 MJ/€	21.9 €/h	291.7 €/GJ
Household sector	**2.8 MJ/h**			

Table 3. Data of key MSIASM indicators for 2005.

sumed in productive activities, although household consumption is growing the fastest.

- The exosomatic metabolic rate in the household sector (EMR_{HH}) is low, but growing very quickly (rising from 1.64 MJ/h to 2.80 MJ/h, at a yearly rate of 3.4%). This means that a large part of the increase in energy consumption was allocated to household consumer goods in an effort to get into line with the other economies in Catalonia's geographical and economic area, in particular the EU countries.

- In the productive sectors taken as a whole, however, the exosomatic metabolic rate grew very little, going up from 159 MJ/h in 1990 to just 167 MJ/h in 2005. This is interpreted as meaning that the extra energy consumed was not used to increase the capitalisation of the productive sectors (with new machinery and infrastructures for existing workers), but was used mainly to provide the new workforce with the necessary equipment to carry out its activity. In other words, there was growth, but no qualitative change occurred.

- Looking at each of the subsectors individually, energy consumption per hour worked in industry (which here includes construction and the energy sector) was 331 MJ per hour worked, with big pro-cyclical variations. In the primary sector it was 178 MJ/h, whereas in the services sector it was 75 MJ/h, and seems to have reached its peak in 2001.

- **The economic efficiency of energy consumption** (ELP/EMR) shows the different sectors' differing degrees of efficiency in making use of energy. Industry generates less value added per unit of energy consumed than the primary sector (see table 2). It should be noted that services generate over four times more value added per unit of energy than industry or the primary sector.

Discussion

- The results presented here show that there is a close relationship between economic growth and primary energy consumption (figure 8). Catalonia consumes more and more energy in both absolute terms and per unit of GDP (it is not dematerialising). If there is no change in the growth model and the structure of the economy, greater GDP growth will always involve greater energy consumption and, therefore, greater external dependency and fragility of the economy, aside from a bigger impact on the environment.

- Given that the population is expected to age in the short term, which will increase the dependency rate, labour productivity in the different sectors will have to increase in order to offset the loss of employed population. Another solution might be to encourage immigrants of working age to come to Catalonia as a way of rejuvenating the population.

- The big increase in energy consumption in Catalonia during the period under study – around 3% per year – did not occur evenly across all subsectors. A large part of the increase occurred in the household sector (4% per year), while in the productive sectors the increase was less marked (2.8% per year on average). Most of the increased energy consumption was in consumer activities and went on improving the population's material standard of living, and not on investment in the productive sector.

- A worrying factor is that the energy consumption per labour hour indicator, or the exosomatic metabolic rate of paid work (EMR_{PW}), in the productive sectors in Catalonia has levelled out at around 180 MJ/h since 1994. As the amount of energy consumed per hour (EMR) and economic labour productivity (ELP) are linked, this levelling out of the EMR indicates that labour productivity has not been increasing.

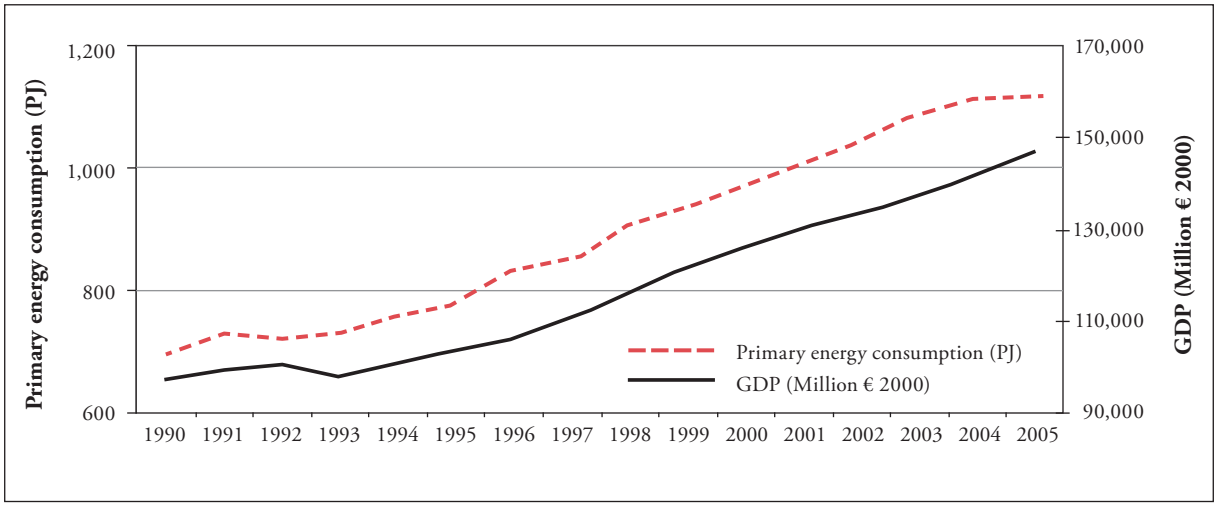

Figure 8. Total primary energy consumption and GDP in Catalonia (1990-2005).
Source: Own calculations from ICAEN (2006) and INE data.

- If this performance stays the same over the next few years, the increased productivity needed in view of the evolution of the population will not be possible unless the amount of energy consumed per hour worked rises in the different sectors, which would lead to increased total energy demand and so increase energy intensity. A second solution would be for a major structural change to occur in the country that would reduce the active population in industry and increase the active population in the services sector (which consumes less energy per hour worked).

- It also needs to be borne in mind that the different economic sectors have different energy mixes. For example, industry consumes mainly natural gas and electricity, whereas services consume mainly oil products. A transfer of active population to the services would lead to lower energy consumption per hour worked. However, a reduction in the amount of energy consumed by industry, if matched by an increase of equal magnitude in the services sector, would actually worsen Catalonia's energy mix.

- In the household sector (including consumption of the 25% of transport) over half the primary energy used comes from petroleum derivatives, almost 30% from natural gas and less than 20% from electricity. Any rise in the EMR_{HH} would have an extremely negative effect, and the impact per unit increase would be worse than if it occurred in industry.

- In conclusion, the results of the analysis demonstrate that the growth model followed by Catalonia since 1990 is heavily dependent on energy consumption and, most worrying of all, it looks as though this trend will be maintained in the future.

- Energy consumption has been used to achieve quantitative growth of the economic system, but not for qualitative "development". No structural shifts have occurred in the productive sectors towards activities that are less energy intensive and generate more value added, so the increased energy consumption has served to absorb new population entering the labour market.

- It seems that Catalonia is specialising in activities that generate low value added and require little education and training (construction and commerce). The lack of innovation and investment in technology mean that labour productivity suffers. This leads into a spiral of specialisation in activities generating little value added, in which the only way to satisfy demand will be with more immigration. To get out of this spiral, technological excellence will have to be promoted in every sphere of activity in order to improve the productivity and the competitiveness of Catalan products.

- To break this strong link between economic growth and energy consumption, saving and efficiency measures, although essential, will not be enough. Therefore, a structural change is needed that will lead the Catalan economy towards less energy-intensive activities.

11. Material flow analysis

In order to provide a global view of the metabolism, the energy study was supplemented by a material flow analysis (MFA) for Catalonia between 1990 and 2004.

In other words, an analysis was made of the amount, type and origin of the materials used by the economy in this period to quantify the materials Catalonia needs to sustain its functioning.

The methodology employed consists in quantifying all the materials entering Catalonia from its own natural environment (agricultural crops, fisheries, mineral extraction) and from other countries, and exports. The methodology standardised by Eurostat (2001), which is applied to numerous countries around the world, was used. Spain has incorporated it into its official statistics.

In overall terms, between 1990 and 2004 all the indicators grew, as did energy consumption:

- Domestic extraction of minerals increased by 70%; adding imports gives the Direct Material Input (DMI), which went up by 60%. The physical trade balance (imports less exports) increased by 16% in terms of mass. Growth in the consumption of materials within Catalonia was noteworthy, rising by 56%. In the same period, primary energy demand rose by 60%.

- Material consumption growth was not constant, but occurred mainly from 1996 onwards, coinciding with the acceleration of energy consumption and a period of economic growth. In large part this was a consequence of the strong growth in the building industry, the leading material-consuming sector. Per capita material consumption in Catalonia went up from 11.8 tonnes in 1990 to 16.9 tonnes in 2004.

An analysis of the evolution of the three categories examined in the MFA reveals the following:

- Only 4% (by weight) of the **fossil fuels** consumed were extracted in Catalonia. Both consumption and imports of fossil fuels grew throughout the period: consumption rose by 24%, from 2.5 to 2.9 tonnes per capita, while the physical trade balance went up by 33%.

- The extraction of **mineral resources** was dominated by quarry products and its derivatives, clearly linked to the construction sector. Most of these resources came from Catalonia's natural environment, but almost all metal minerals were imported. The heavy consumption of mineral resources and construction materials has direct implications for Catalonia's energy metabolism. On the one hand, it is associated with high energy consumption processes, such as the manufacture of cement, while on the other, transport of building materials accounts for a large part of the goods traffic.

- Consumption of **biomass** (produced in agriculture, livestock farming, fishing, forestry and derived products, such as processed food) grew by 28% between 1990 and 2004. There was a big increase in imports, up by 60%, and exports, up by 71%. The amount of biomass consumed in Catalonia is double the amount produced.

- As regards foreign trade, Catalonia is heavily dependent on imports for its energy, metal minerals and biomass resources and this dependency grew throughout the period. Both imports from and exports to the rest of Spain and other countries increased in quantity and became more diversified, giving rise to a big need for goods transport.

- The trends in Catalonia are similar to those in the rest of Spain, but both Domestic Extraction (DE) per capita and Domestic Material Consumption (DMC) per capita are lower in Catalonia. However, per capita energy consumption is higher in Catalonia.

- Biomass consumption per capita in Catalonia is very low in comparison with other EU-15 countries, while use of fossil fuels is only slightly below the average. Catalonia is one of the countries with the highest consumption of mineral resources, above the European average. This fact is linked to the activity of the construction sector.

- Catalonia is also heavily dependent on imports for materials in general, a situation that is typical of small countries with scarce resources of their own, such as Belgium, Luxembourg and the Netherlands.

- In conclusion, the material flow analysis for Catalonia between 1990 and 2004 shows a high degree of materialisation in both absolute and relative terms, with material consumption, like energy consumption, growing faster than GDP. This means that with Catalonia's current metabolism, economic growth brings with it increased material and energy needs, so the economy is becoming more and more inefficient in its use of natural resources.

- Policies are required that will modify the current growth model, in which construction plays a big part, in order to reduce the consumption of resources, the extraction of minerals from the natural environment, imports and goods transport.

12. Conclusions

Focusing first on the **energy system**, the main conclusions are:

- The strong tendency for primary energy consumption to increase (60% in 15 years), which is expected to continue in the future, means that moderating energy consumption must be one of the priority energy policy goals. This can only be achieved by combining energy policy with other regional development and economic policies.

- To tackle the heavy dependency on fossil fuels (over 75% of primary energy), greater diversification of sources, particularly the use of renewable energy sources, is needed.

- Oil is used in Catalonia for purposes which may be called "structural": 45% for transport, 25% for non-energy uses (the petrochemical industry). Only 2% is used for generating electricity.

- External dependency is a major problem and so the countries from which energy is imported (and in the case of gas, the way it is imported – as LNG or by pipeline) need to be diversified. Only 4% of the primary energy consumed in Catalonia comes from indigenous (mainly renewable) sources.

- Renewable energy sources contribute very little (less than 3% of primary energy). Therefore, a study needs to be made of the obstacles to increasing their share (especially the issues around wind energy) and policies need to be put in place appropriate to Catalonia's requirements. It should be remembered that both current levels and forecasts of the use of renewable energies in Catalonia are well below the European targets (12% of primary energy from renewable sources by 2010; 20% by 2020), whereas it is expected that these targets will be achieved in Spain as a whole.

- The use of biofuels for transport involves considerable problems, so they are not an appropriate solution on a large scale, although it is important to support the production of biodiesel from used cooking oil[8] or waste. Large-scale plantations and imports should be avoided. Efforts should be focused on reducing fuel demand for transport.

- The present energy model generates a number of environmental impacts. Simplifying to a great extent, the most important of these are nuclear waste (for which there is no definitive solution at the moment) and greenhouse gas emissions (which in Catalonia have gone up by 60% since 1990, well above the Kyoto commitments, and are expected to continue rising).

- The Catalan energy system is extremely centralised: there are few production centres and they are a long way from the main consumer areas. Existing and planned infrastructures make the shift towards a distributed generation model rather difficult.

- Catalonia has the challenge of facing up in the near future to the gradual closure of the nuclear power stations in its territory (planned to start in 2022). Although the decision is the responsibility of the Spanish central government, the discussion needs to be started now so as to be prepared for implementing more sustainable alternatives.

The main **proposals** in this connection are:

- To contain and reduce the demand for energy, in particular:

– To reduce the consumption of transport fuels: improving the public transport network, prioritising railway infrastructures over roads, promoting goods transport by rail, reducing mobility needs by regional and town planning policies.

– To reduce the demand for electricity from households and services: putting in place saving and efficiency policies, checking urban expansion, applying the building technical code and the ecoefficiency decree, introducing renewable energy sources and demand-side management systems, and encouraging bioclimatic architecture. Energy saving must be one of the pillars of energy policy, including both changes in habits and improved efficiency in the use of energy.

- To reduce dependency on oil: in the short term, diversifying the origin of imports; in the medium term, reducing society's need for oil. In order to safeguard competitiveness, maximum efficiency in oil use by industry must be pursued. Alternatives to the most inefficient uses in energy and value added terms, such as transport, must be sought.

- To promote renewable energy. The impediments and difficulties involved must be examined and a Catalan policy of promoting renewable energy put in place. It is extremely important to foster research, development and innovation in this area.

8. Collection of used cooking oil is still not very common in Catalonia. It ought to become more widespread in order to reduce water pollution and treatment costs.

- To take better advantage of energy resources, with co- and tri-generation systems in towns and cities (district heating) and in industry.

- To promote research and development in renewable energy, and energy saving and efficiency.

- Catalonia must have a strong institutional framework. An important step forward in this direction could be the setting up of a Catalan Energy Agency.

The conclusions regarding **energy use in the Catalan economy** are:

- Catalonia's growth model since 1990 has been heavily dependent on energy consumption. Moreover, energy consumption has been growing faster than GDP (by 3% a year, as against 2.6%) so that Catalonia's energy intensity has increased. This means the economy has become less efficient in its use of energy for generating value added.

- There have been no structural changes in the Catalan economy. Increased energy consumption has served to absorb new population entering the labour market and provide it with the necessary infrastructures and means of labour.

- Economic labour productivity (ELP) did not grow in the period under study, which means the economy became less competitive. Moreover, there were enormous differences in the amount of energy consumed per hour worked between different economic activities and the fact that this amount grew very little partly explains the negative evolution of labour productivity. If this stagnation continues in the future, the competitiveness of Catalan production will decline even further.

As far as the analysis by **sectors of activity** is concerned:

- Catalonia has been steering its activity towards services, with transport accounting for an increasing share, as other industrialised economies have done before it.

  The amount of energy consumed per hour worked has grown very little. This is interpreted as meaning that the extra energy consumed was not used to increase capitalisation of the productive sectors (with new machinery and infrastructures for existing workers), but to provide equipment for the new workforce.

- The energy transformation sector is the one that consumes the most energy, but its efficiency has improved and the energy mix has changed. It accounts for 16% of CO_2 emissions.

- The primary sector consumes very little (3% of the total primary energy consumption), but more than 90% of what it does consume are petroleum derivatives. The amount of energy consumed per hour worked is very high in the primary sector in Catalonia compared to that in the rest of Spain.

- Industry (including construction) accounts for 22% of primary energy consumption and produces 29% of CO_2 emissions. Its metabolic rate in 2005 was 333 MJ/h, but was subject to big cyclical fluctuations. Nevertheless, industry's economic productivity is lower than agriculture's, which points to the urgent need for investment in sectors that require less resources and generate more value added.

- The service sector has grown very quickly, although it still accounts for only a small fraction (8%) of primary energy consumption. It demonstrates the process of the tertiarisation of the economy and increasing energy intensity. It is the sector with the highest economic productivity in its use of energy. And its labour productivity is on a par with industry's.

- Transport consumes about 24% of primary energy, but generates 46% of CO_2 emissions. The trend is for this to rise with the Catalan economy becoming more and more dependent on transport for its functioning. Transport's total dependence on oil means that radical measures are required to change the mobility model.

- The household sector has also been increasing its energy consumption very rapidly. This is due to the spectacular increase in society's material living standard and the increase in population. The Catalan population is forecast to continue growing over the coming years and so new households will be set up and need equipping. On the other hand, energy consumption per hour not worked is still low in comparison with the other economies in Catalonia's geographical and economic area, which makes it likely that it will increase. It is linked to families' material standard of living (new consumer goods and equipment, travel and leisure).

- Catalonia has shown a strong tendency to converge with the European average in regard to most of the variables analysed (figure 9). Energy intensity has approached the EU-15 average (7.9 MJ/€ in 2004), although the other countries in the same geographical and economic area as Catalonia have exhibited a clear downward trend, while in Catalonia (and

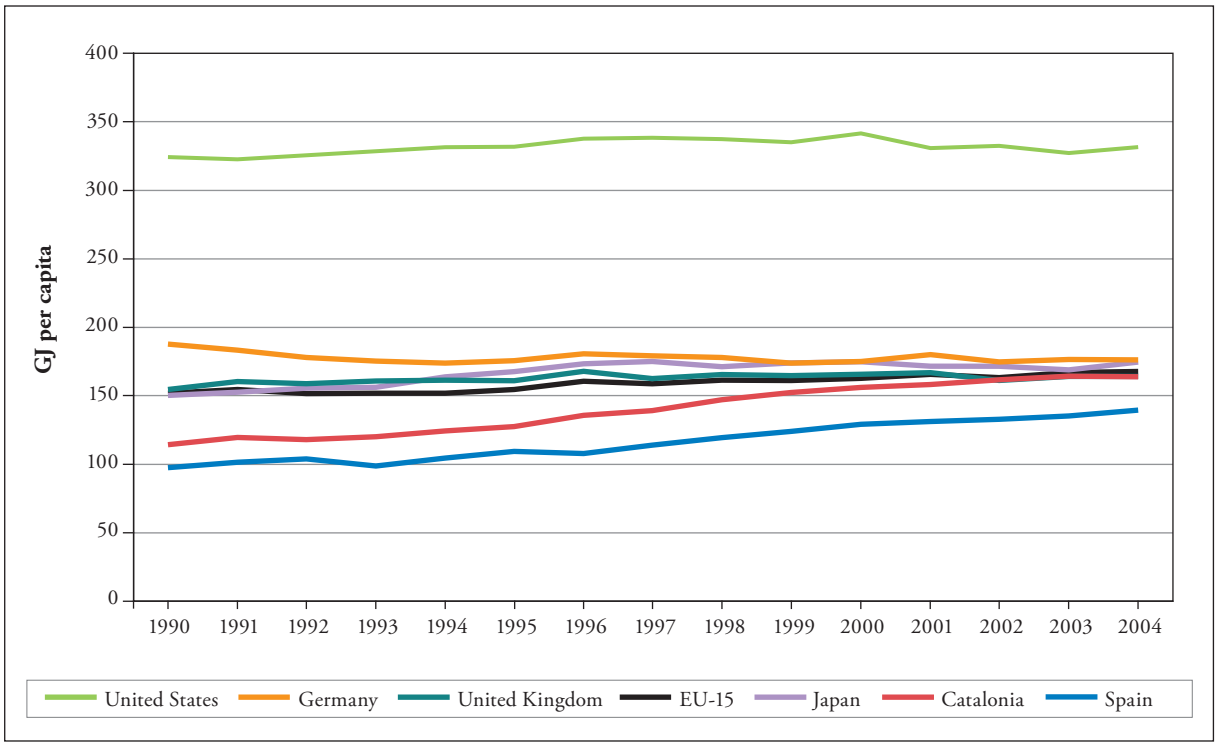

Figure 9. Per capita primary energy consumption (GJ) in different countries.
Source: Own calculations from IEA (2006) and INE data.

Spain as a whole) the trend has been upwards. This increased energy consumption was also seen in per capita consumption, which moved closer towards the European average.

In regard to **action proposals** in this sphere:

- Economic and fiscal instruments have not yet been used sufficiently in Catalonia for energy management. There is a need to continue with the line of providing grants and subsidies to promote renewable energy, savings and efficiency. At the same time, there is a need to look at whether there are subsidies and exemptions currently available that may have a perverse effect in terms of energy consumption and, if they exist, reduce them.

- *In transport*: Changes are needed in mobility, goods transport and infrastructures, which today encourage private car use. A shift towards more efficient ways of satisfying transport needs, such as the railway for goods and public transport for passengers, must be promoted.

- *Construction and town planning*: Energy criteria must be introduced into construction (applying the current legislation on ecoefficiency and new measures based on bioclimatic architecture) and in regional planning, such as promoting compact cities and mixed uses.

- *Infrastructures*: The energy consequences of the new transport infrastructures must be taken into consideration, as they establish the future model of mobility and shape habits.

- *The household sector*: Steps should be taken to encourage owners of old housing to incorporate the measures provided for in the new technical building code into all housing and continue the campaigns to promote energy efficiency and savings. Citizens must be made to share the responsibility for actions to reduce energy demand and its impact on climate change. A more detailed analysis is required, as this will be an important sector in the future.

- *In industry*: The sectors with the highest value added, which are often those incorporating most technology, must be strengthened. Taxation could play a part in this by means of a levy on SO_x, NO_x and CO_2 emissions to encourage energy savings and a changeover to cleaner and more efficient sources.

- *In the energy sector*: Steps must be taken to boost the introduction of least cost planning criteria, which foster demand control over supply control measures in energy planning. There are many things that could be done via taxation (for instance, imposing a levy on the use of sources with the biggest impact).

- *The different tiers of government* have available to them instruments such as green purchases, incentives and energy management measures such as investment recycling, taxes, etc. In the institutional sphere, the ICAEN should be turned into an Energy Agency with enlarged powers.

Identification of key points

Main weaknesses

- The heavy dependency on oil imports puts Catalonia in a fragile position in the event of future price rises or a relative scarcity of oil.

- Construction plays a very big part in the economy and consumes a large amount of energy (manufacture of cement, transport of materials). Moreover, it exerts an influence on future consumption, so improvements need to be made in this sector.

- The transport sector is one of the main consumers of energy, almost all of it petroleum derivatives. The economic and regional structure makes it difficult to contain energy consumption by transport.

- Labour productivity and the amount of energy consumed per hour worked have levelled out. This may be an indication of improved efficiency, but is more likely to reflect stagnation in productive investment.

- Population growth means that the amount of energy consumed by households will rise.

- The future closure of the nuclear power stations poses some difficult challenges. A discussion needs to be started so as to have alternatives for when this happens.

- Care must be taken over the choice of natural gas in industry and for the generation of electricity, as it may give rise to the same type of problems as oil in the near future. In addition, major investment will be needed to improve the infrastructures.

- If current trends are maintained, there will be a big increase in energy-related greenhouse gas emissions.

- From an institutional viewpoint, there are limitations on the distribution of powers among the different tiers of government.

Main opportunities for Catalonia

- Catalonia ought to make the most of the present need to rethink its energy model in order to reposition itself as a region leading the way in research on and application of energy efficiency measures and renewable energy. This would give the Catalan energy industry a competitive advantage and improve the competitiveness of the sectors of the economy in which such measures and energies were implemented.

- Although Catalonia has no obligation to meet the EU targets, they could be accepted as its own and serve as a stimulus.

- The need to reconsider its energy model means that Catalonia has the chance to design a transition to the marketing of energy services instead of units of energy.

- It would be useful to take advantage of the synergies with climate change policies, both in regard to mitigation measures (reduction of fossil fuel consumption and improved efficiency) and adaptation (for example, harnessing of the biomass from improved forestry management).

- Advantage must also be taken of the fact that climate change has a prominent place in the media in order to get across the need to make proper use of energy resources.

- Energy policies must make the most of the synergies with other policies such as regional, economic, industrial, environmental, mobility and infrastructure polices.

Lastly, it should be pointed out that a shortage of energy, economic and demographic data on Catalonia has been detected, which exerts an important limitation on research. In particular, the energy balance sheets for Catalonia need to be published and the most detailed possible breakdown of energy and economic data is required. In this connection, the different methodologies used in this study to carry out in-depth analyses and generate various scenarios, in particular the use of the MSIASM, should allow those responsible to take informed decisions regarding future energy scenarios that are economically viable, socially acceptable and more respectful of the environment, and will reduce the risks associated with the heavy energy dependency from which Catalonia suffers at the present time.

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Abbreviations and acronyms

AG Agriculture (in the MSIASM)

AMEEC Analysis of the Energy Metabolism of the Catalan Economy

DE Domestic Extraction (in the MFA)

DMC Domestic Material Consumption (in the MFA)

DMI Direct Material Input (in the MFA)

ELP Economic Labour Productivity

EMR Exosomatic Metabolic Rate (in the MSIASM)

EROI Energy Return on Investment

GDP Gross Domestic Product

GVA Gross Value Added

HH Households (in the MSIASM)

ICAEN Catalan Energy Institute

IDESCAT Statistics Institute of Catalonia

IEA International Energy Agency

IER Intensive Renewable Energy Scenario (in the PEC)

INE Spanish National Institute of Statistics

LNG Liquefied Natural Gas

MFA Material Flow Analysis

MSIASM Multi-Scale Integrated Analysis of Societal Metabolism

NO_x Nitrogen oxides

OECD Organisation for Economic Co-operation and Development

OPEC Organisation of Oil-Producing Countries

PEC Energy Plan of Catalonia 2006-2015

PER Renewable Energy Plan for Spain 2005-2010

PS Productive sector (in the MSIASM)

PW Paid Work sector (in the MSIASM)

SA Society Average (in the MSIASM)

SG Services and Government (in the MSIASM)

SO_x Sulphur oxides

TEQ Tradable Emission Quotas

UE-15 15-Member European Union

Main units used

mbd = million barrels per day

GJ = Gigajoule (10^9 joules)

MJ = Megajoule (10^6 joules)

MW = Megawatt (10^6 watts), a unit of power

toe = tonne of oil equivalent, 41,868 MJ

ktoe = thousand tonnes of oil equivalent

Summary and key words

The *Analysis of the Energy Metabolism of the Catalan Economy* (AMEEC according to its initials in Catalan) examines how energy is used in the different economic sectors and in the economy as a whole, on the basis of economic, demographic and energy data. The study sets out the main challenges facing the Catalan economy in the international context of an energy crisis. It shows, among other things, that there is a close link between economic growth and energy consumption between 1990 and 2005, a period of increasing energy intensity. Both labour productivity and the amount of energy used per hour worked remained the same. The use of fossil fuels (oil and gas) accounted for three quarters of the primary energy used in the period, and entailed a large amount of CO_2 emissions and heavy external dependency. Use of renewable energies is still very limited, something which urgently needs to be rectified if the targets of the Energy Plan for Catalonia are to be achieved. The study, commissioned by the Advisory Council for Sustainable Development in 2006, concludes that energy policy must put in place measures to moderate consumption by means of savings and efficiency strategies at all levels in regard to both final use and transformation. In addition, these measures must be accompanied by appropriate regional development, economic and industrial policies, and advantage must be taken of synergies with climate change policies. The main key sectors in which action needs to be taken are transport and the promotion of alternative energies.

Key words: energy, energy policies, renewable energies, Catalonia, energy metabolism.