A NEW ENERGY MODEL FOR SPAIN

RECOMMENDATIONS FOR A SUSTAINABLE FUTURE

WORKING GROUP OF FOUNDATION IDEAS FOR PROGRESS
ON ENERGY AND CLIMATE CHANGE

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Recommendations for a sustainable future

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Glossary

AEC: Atomic Energy Commission

AGR: Advanced Gas Reactor

ANDRA: Agence nationale pour la Gestion des Déchets radioactifs (France's National Radioactive Waste Management Agency)

BAU: Business as usual

bb: Busbars

BCG: Boston Consulting Group

BOE: Official State Gazette

C-22: An alloy made mainly of nickel, chromium and molybdenum, designed to pack fuel waste and highly toxic waste.

CAES: Compressed Air Energy Storage

CC: Carbon Capture

CCAA: Autonomous Communities (Spanish Regional Governments)

CCOO: Comisiones Obreras (One of the two major trade union confederations in Spain)

CEO: Chief Executive Officer

CF: Capacity Factor

CFR: Council on Foreign Relations

c/kWhe: Dollar cents per kilowatt hour of electricity

CNAE: Spanish National Classification of Economic Activities

CNE: Spanish National Energy Commission

CORES: Corporation of Strategic Reserves of Oil Products

CTC: Costs of Transition to Competitors

CTE: Spanish Building Technical Code

CWIP: Construction Work in Progress

Dbb: Demand at busbars

DCE: Deficit Cost Estimate

DOE: Spanish Energy Department

E: Exponent

E4: Spanish Energy Efficiency Strategy

EBR: Experimental Breeder Reactor

EBS: Engineered Barrier System

EC: European Commission

EDF: Electricité De France

EDZ: Excavation Damaged Zone

EIA: Energy Information Administration

EPA: Energy Policy Act

EPR: European Pressurized Reactor

FEST: Special Fund for Transport Sustainability

FPL: Florida Power&Light

FSOC: Fractional State of Charge

GAO: Government Accountability Office

GDP: Gross Domestic Product

GHGH: Greenhouse Gas emissions

GNEP: Global Nuclear Energy Partnership

GtC: Gigatonnes of Carbon

GW: Gigawatt

GWe: Gigawatts of electricity

GW/y: Gigawatts per year

HDR: Hot Dry Rock

ICE: Internal Combistion Engine

IDAE: Spanish Institute for Energy Diversification and Saving

IEA: International Energy Agency

IEER: Institute for Energy and Environmental Research

INE: Spanish National Statistics Institute

IPCC: Intergovernmental Panel on Climate Change

ISTAS: Spanish Trade Union Institute for Labour, Environment and Health

ITS: Integrated Transport System

IU: Izquierda Unida (Spanish left-wing party)

ktep: Kilotonne

kW: Kilowatt

kWh: Kilowatt hour

kWh/p-d: Kilowatt hour per person and day

LPG: Liquefied Petroleum Gas

M.inhab: Million inhabitants

MIT: Massachussetts Institute of Technology

MITYC: Spanish Ministry of Industry, Tourism and Trade

MOX: Mixed Oxide. Nuclear fuel made of uranium and plutonium.

mrem: Millirem

$MtCO_2$: Million tonnes of CO_2

Mtoe: Million tonnes of oil equivalent

MWe: Megawatts of electricity

NA: Not available

NEI: Nuclear Energy Institute

NPT: Nuclear Non-Proliferation Treaty

NRC: Nuclear Regulatory Commission

NREL: National Renewable Energy Laboratory

NWTRB: Nuclear Waste Technical Review Board

O&M: Operations and Maintenance

PAE4: Saving Plan within the Spanish Energy Efficiency Strategy

PAEE 2008-2012: Spanish Energy Saving and Efficiency Plan

P_bio: Biomass power

PE: Primary Energy

PER: Spanish Renewable Energy Plan

PEF: Progress Energy Florida

P/P_max: Quotient between instant and maximum power throughout the year

PP: Partido Popular (Spanish right-wing party)

PSOE: Partido Socialista Obrero de España (Spanish socialist party)

PV: Photovoltaic

PWR: Pressurized Water Reactor

RD: Royal Decree

R&D: Research and Development

R&D&I: Research and Development and Technological Innovation

RE: Renewable Energies

REE: Spanish Electrical Network

RES: Renewable Energy Sector

SGE: Spanish State Department for Energy

SM: Solar multiple

STUK: Säteilyturvakeskus (Finland's Radiation and Nuclear Safety Authority)

TMI: Three Mile Island

TVA: Tennessee Valley Authority

TVO: Teollisuuden Voima Oyj – Finnish electricity company building a new nuclear power station

TWh/a: Terawatt hour per year

V2G: Vehicle to grid

WEO: World Energy Outlook

WETO-H2: World Energy Technology Outlook – 2050 (European Commission – Directorate for Research)

Wh/km: Watts/hour/kilometre

WNA: World Nuclear Association

YM: Yucca Mountain

Executive Summary

Spain, and other countries throughout the world, faces a major historical challenge in the forthcoming future as a result of climate change and the depletion of fossil fuels. Spain cannot afford to look away, but must rather lead the field in providing European responses so as to overcome these challenges. We must bear in mind the fact that decisions taken today will have a fundamental effect on the future of many coming generations, and ensure that such decisions respond to the need for a public, meaningful, transparent exchange of ideas.

A wide range of opinions has been expressed in response to this concept, not always well-informed, and often one-sided. However, the sustainability of our economic model is a basic issue which requires a global approach derived from an objective analysis that includes all variables bearing on Spain's, and the world's, present situation.

Our world needs an energy model founded on "sustainable development" to satisfy current needs without compromising options for future generations who, in turn, must fulfill their own demands. Spain must consolidate its existing technological leadership in renewable energy during the transition towards this new model, and become a global example in proving the viability of a sustainable economy in its role as one of the world's most advanced economies.

At the same time, a change in the Spanish production model towards a sustainable alternative will prove to be a cornerstone in ensuring a solid, long-lasting economic recovery. All these reasons have prompted the Ideas Foundation to call upon a group of Spanish and international expert to draft a report providing a global, realistic view of Spain's energy framework, to enlighten society regarding the existing energy model, and to establish the bases required for a transition to an up-to-date, sustainable energy model.

An untenable existing model

The existing energy model is not tenable due to high levels of energy consumption and of polluting emissions, as mentioned in various International Energy Agency (IEA) documents. Spain, and the world at large, must seriously consider the present situation and resolve the need for a new energy model aimed at ensuring a dependable energy supply while, at the same time, protecting the environment.

We are undoubtedly facing the end of an era, that of fossil fuel, and look to the dawn of a new Industrial Revolution, whose foundations will be renewable energy sources.

The main component in today's Spanish model is an absolute reliance on fossil fuels sourced from abroad, up to 90% of total consumption, dooming the country to permanently depend on the inconstant swings of world crude and natural gas markets. If Spain is to play an important role on the world stage it must do away with this overwhelming energy dependence and decisively support its domestic renewable-energy market.

Energy dependence makes a country highly vulnerable, but this is not the only challenge posed by conventional energy sources. All relevant analyzes share highly pessimistic forecasts concerning existing reserves of the most significant energy sources. If reliance on existing energy model continues, the main global reserves of oil, natural gas, oil, and uranium, will be depleted within decades. It is therefore not a question of deciding on the energy model of choice, but rather of economic forecasting to ensure a future energy source of supply and the sustainability of the planet as we know it.

There are those who, in this context, see nuclear energy as the ideal solution to overcome these concerns. However, nuclear energy continues to involve issues which advise against its generalized use. Some of the more important considerations include the scarcity of uranium required to satisfy mid-term global demand, problems arising from the need to store radioactive waste for tens of thousands of years, and the complexities resulting from security issues and nuclear proliferation. The cost of construction of nuclear plants, which reach 7 billion Euros in the latest unit currently being built in Finland, necessarily involves direct public investment.

Nuclear power alone cannot satisfy future energy needs while protecting the environment, both of these within a sustainable model. It will probably prove impossible to replace currently operating reactors by new generation units once they have completed their scheduled service life, which will undoubtedly take place by mid-century.

Renewable energy: a dynamic, innovative reality in Spain

The past five years have shown that the political and business decision to support this sector in Spain is no myth. In a very brief span of time renewable energy has firmly established itself and proven its copious environmental, financial and industrial potential in this country. The contribution provided by renewables to the Spanish energy mix has witnessed exponential rates of growth. A very few years ago only a handful of experts foresaw the speed and size of this development, but hard facts speak for themselves. Still, there are some who decry the future of this sector. They would rather turn their gaze elsewhere, towards the past. They wish not to see that there is no future beyond renewable energy, and that it has become an unstoppable reality in Spain.

Spain relies on one of the world's most dynamic and advanced renewable energy sectors: the country is a global leader in terms of technological production and innovation. This sector has exporting capacity, and is a model for some of the more important economies, including Obama's USA.

Official data show the significant financial and industrial repercussions of renewable energy in Spain. This sector currently employs 175,000 workers nation-wide, of whom 82% are under open-end contract, making it one of the more stable and productive components of the economy, much more so from the labor point of view than conventional energy.

We should also mention that potential job creation, and the penetration of Spanish companies in international renewable energy markets, place this sector in an improved position, when compared with conventional or nuclear energy in defining future energy models.

A new energy model for Spain towards the year 2050

In this text the Ideas Foundation proposes a new energy model for Spain, free of CO2 emissions and of nuclear energy by 2050, with the capacity to satisfy 100% of energy demand through renewable sources.

The various simulations provided by the authors indicate that Spain can rely on more than sufficient resources to decisively pursue its efforts towards a new configuration of the national power generation system, and aim at a new model based only on renewable sources. To this end there is a large array of resources available, both in terms of generation and of demand, whose timely implementation will allow the economy to comply with conditions governing the transition period. This will require quick reactions to very limited response times while limiting the cost of the resulting energy system. The only significant barrier is the need to define and maintain a favourable context, over time, in order to promote the rapid growth of these technologies through legislation that may ensure long-term stability.

In our opinion, there is no doubt that power demand can be fully met through the use of renewable energy given the available potential, results of in-depth analyzes, and instruments on hand, to guarantee the viability of the various generation mix models under consideration. The issue, rather, refers to the specific elements and components in the different mix proposals, which set the framework for the political and regulatory decisions necessary in defining a new direction for developing a sustainable energy system within the short time available.

We have decided, in this text, to address a number of options to fully satisfy demand for electric power through renewable energy sources according to three consumption models (high, medium and low demand). The elements within this bracket include all possible future scenarios involving power needs in Spain by the year 2050. In other words, even if Spain continues to consume energy at the current high rate, within the different population and economic model forecasts, it would be possible to satisfy such demand by using renewable energy if these sources enjoy the adequate incentives and support.

Renewables-based generation mix models discussed in the text may be seen as a conservative approximation, in the sense that they assume a limited presence of demand-management components and impose a minimum diversity on the generation mix structure. This could result in renewables-based power system configurations requiring lower levels of installed capacity.

The scenarios discussed in the text show that for mid-level demand values it would be possible to implement a complete shut-down of nuclear power plants by the year 2016 on the basis of the installed capacity of renewable energy sources without increasing consumption of fossil fuel. Nonetheless, a total write-off of fossil fuel within the power generation system markedly depends on flexibility, specifically in generation, which must be part of the many stages towards a renewables-based generation mix by 2050.

Electric-powered transport in Spain by 2050 is a challenge which could turn out to be an opportunity for increased economic development in both the domestic and global markets. This would require incorporating know-how and industrial capacity, as well as innovation, currently available in key areas such as renewable energy and the automotive sector, in the latter case particularly the replacement and spare parts subsector, mandatory for a transport system based on renewable electricity. This would, in turn, need a technological-industrial cluster charged with developing this potential supported by significant financial investments for R+D+i.

Electric cars are a necessary component in completing a 100% renewable electric energy system. A suitable model involving electric technology and electric motors, timely and sustained over the long term, will lead to a transport framework based on domestic renewable energy sources within the time scale discussed in this text, that is, by 2050.

However, one of the fundamental elements in the decision to pursue a new energy model in Spain is the industrial and labor component. Renewable energy creates more jobs than conventional energy. Depending on the demand scenario, a transition to a new energy model could lead to the creation of between 292,531 and 1,188,871 jobs. These will also be more stable and require higher qualification and training than the conventional energy sector.

The new energy model represents a historic opportunity to bring about change in Spain's economy. If the renewable energy sector maintains current rates of growth in Europe, Spain could be looking at a potential market of some 2 or 3 trillion Euros.

Other basic factors included in the package necessary for creating the new proposed system are a regulatory framework involving command and control initiatives, a bonus system, tax breaks, and priority access to the existing energy mix for renewable energy sources.

Achieving a new energy model based on 100% renewable energy, totally divested of coal and nuclear power, is the responsibility of society as a whole, while the Government must act as catalyst and facilitate cultural, economic and social changes necessary within this process. It is our opinion that a clearly-defined strategy must be instituted, including a schedule of actions and specific, quantified targets, to guarantee the transformation of the existing model to the new, forward-looking future model we propose.

Public authorities at all levels and the key social agents – particularly the business sector – must take on a leadership role in making available the investments required to establish this new model. We should consider this challenge as a strategic point in our country's agenda. The new model will ensure strengthened energy independence and consolidate our role among the most innovative nations within the global market.

Recommendations made by the Ideas Foundation

This report submitted by the Ideas Foundation closes with several recommendations for managing the change in the national energy model by 2050 addressed at public authorities and society as a whole.

Some of the more important recommendations towards implementing a 100% renewables target include the following:

a. The Government should reassert its commitment to EU energy policy objectives concerning climate change and towards Horizon 2020: a 20% reduction in emissions, 20% reduction in consumption of primary energy, 20% renewable energy mix.

b. The Government should approve a new Law on Sustainable Energy which includes, as long-term target for 2050, an emission-free, fully non-nuclear, electric power system based on 100% renewable energy and an intelligent generation and distribution network with the necessary storage capacity and demand management capabilities.

c. The Government should guarantee, through legislation, an incentives system suitable to support the deployment of a renewables-based electric generation mix, stressing the importance of distributed generation systems. To this end our proposal is to legislate a new Charter Law on Citizens' Rights so that all citizens who so wish may generate and distribute their own energy, individually or in partnership with existing generation and distribution utilities, within a new business model.

d. The Government should include this sector as one of the priority areas for public action as part of its economic recovery programs towards promoting job creation and economic activity, as well as in pursuit of a stronger global positioning for Spanish renewable energy companies. This would also mean including initiatives for energy efficiency and energy savings in Spanish households within those programs, so as to exit the current economic crisis under better conditions.

e. The Government should institute an initiatives program for the Spanish power grid (Red Eléctrica Española) and power utilities so that they may begin modernising transport and distribution networks. This action would make it possible to foster a more rational energy consumption system, better adapted to generation capacities in the new energy model.

f. The Government should foresee the need to substitute nuclear power by other energy sources, so that future energy scenarios include a programmed shut-down schedule of existing nuclear power plants and appropriate management of nuclear waste, still waiting for a solution and inherited from the past.

The Nuclear debate in Spain:

Concerning the ongoing public debate regarding nuclear power within Spanish society, and the forthcoming decisions which the Government must take on this issue, this analysis suggests the following recommendations:

- The Ideas Foundation report believes it unnecessary to build new power plants in Spain.
- The existing nuclear plants in Spain should start closing by the time the existing licence expires, after 40 years of service life, taking into account the following 5 conditions:
  - Safety: should any of them present some safety problem, it should be closed before the expiry date.
  - Substitutability: they shall be closed once there are alternative renewable energies that do not produce emissions
  - Supply: they shall be closed when their substitution does not cause any problems in energetic shortage. In this sense, it is important to apply the recent agreements between Spain and France in order to facilitate the connection with Europe.
  - Manageability: they shall be closed to be substituted by alternative sources of energy to allow a more adequate management of the energetic demand.
  - Competitiveness: they shall be closed to be substituted by equally competitive alternative sources of energy.
- As far as the Garoña nuclear plant is concerned, in operation since 1970, our recommendation is that the Government should notnot renew the operating license due to its age, potential security problems, and the possibility of complete substitution by renewable energy sources. In any case, a future shut-down of the Garoña facility and other nuclear plants should in all cases follow a Reactivation and Employment Plan for the region.
- All other nuclear plants should be subject to the 40-year limitation under the 5 conditions listed above. However, if for any reason whatsoever it proves necessary to extend operation in a given plant, any subsidy payments financed through the plan for compensation of Costs of Transition to the Competition (Costes de Transición a la Competencia). Depreciation and amortization of these subsidies should be included in accounting procedures. This would require implementing a new mechanism to compensate the nuclear sector (as established in the White Paper for Electricity). This new expenditures mechanism would result in savings of public funds and make financing alternatives available to foster nuclear company investments in renewable energy sources to replace nuclear power.

1 Weaknesses of the current energy model and a view for the future [1]

1.1 Introduction

The most important specific collective task which any society should take up in the current situation is clear and simple: radically cutting down the combustion of fossil substances containing carbon. This needs to be done without waiting to see if climate change is as true and intense as they say and regardless of what the rest do, which is the so far traditional small-minded attitude typical of more developed countries.

Considering this problem, climate change, as the main issue associated to our energy system should not make us forget the shortage of conventional energy sources (oil, natural gas, uranium and carbon) and the dependency of some countries such as Spain regarding their supply.

Neither must this task hinder taking into consideration the serious inequality that exists in the use of energy. While some waste it, and that abuse is the main origin of current and future problems, many others (approximately two thousand million) do not have access to a minimum consumption of the so-called commercial energy forms, such as electricity and fossil fuel products. Furthermore, those countries which consume more than necessary consume intermediate forms of energy (electricity and fossil fuels) not thinking about where they are produced and how they reach the points of consumption in the large cities with a NIMBY[2] attitude. This comes to the fore, whenever new electricity lines have to be set up or new substations or oil refineries have to be built. These are all inconvenient, so they are pushed back into the neighbour's backyard. The clearest example in Spain is Madrid and its environs, but the same can be said of Seville, Barcelona or any other large city.

We need to seriously consider a change in our energy paradigm at a personal, local, national, regional and world level with these basic, simple ideas as a starting point.

In this first chapter, we are going to sketch out the lines which we consider essential in order to work out a solution to the problem and tackle this change in paradigm.

1 This chapter is a cut down version of the contributions made by Valeriano Ruiz Hernández, Professor of Thermodynamics at the University of Seville and José Luis Manzano Seco, Industrial Engineer and Chairman of Electria (Electricity company for Sustainable Development).

2 Not In My Back Yard (no en el patio de atrás).

1.2. Analysis of the weaknesses of the current model

The world energy scenario is characterised by the following essential features:

1.2.1 Exponential increase in demand

Even though demand trends vary depending on the degree of development, it is forecasted that developing countries will contribute approximately 74% of the increase in the global demand for primary energy between 2005 and 2030.

Table 1.1: Global demand for primary energy

	2005		2015		2030		2005-2003**
	Mtpe	% /total	Mtpe	%/total	Mtpe	%Mtpe	
Carbon	2.892	25%	3.988	28%	4.994	28%	2,20%
Oil	4.000	35%	4.720	33%	5.585	32%	1,30%
Gas	2.354	21%	3.044	21%	3.948	22%	2,10%
Nuclear	721	6%	804	6%	854	5%	0,70%
Hydroelectric	251	2%	327	2%	416	2%	2,00%
Biomass and waste	1.149	10%	1.334	9%	1.615	9%	1,40%
Other renewable energies*	61	1%	145	1%	308	2%	6,70%
Total	11.428		14.362		17.720		1,80%

* Includes wind, solar, geothermal,
** Average annual growth rate

Despite the fact that in many industrialized countries carbon consumption has gradually decreased, emerging economies and developing countries identify this fuel as the most feasible option. Complying or not with the Kyoto Protocol represents a reference vector.

China and India will represent 45% of the increase, and the level of consumption of primary energy in China will be greater than that of the United States from 2010.

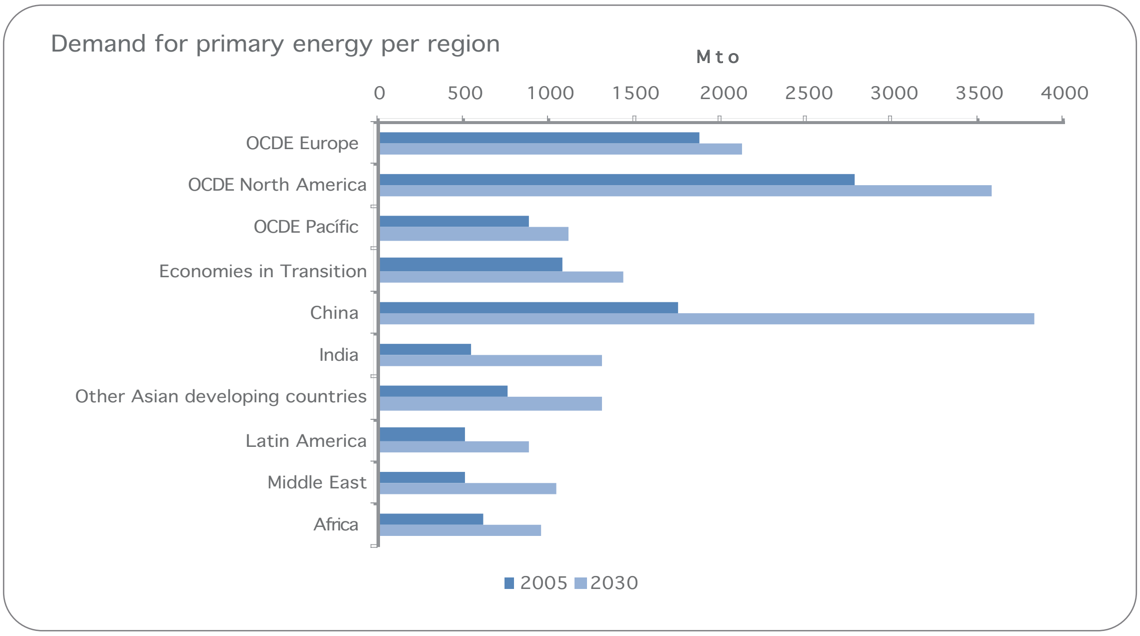
Oil consumption for cars will follow a similar process; consumption will drop in the first group due to improvements and saturation in vehicle fleets and there will be a spectacular increase in demand in the second group.

The progressive but imminent entry of electric cars and the reasonable need for the energy required to charge them to come from renewable sources pose a challenge which must be solved by the new energy model.

The scarce increase in Renewable Energies shows a very conservative or even pessimistic view which will no doubt be very positively affected by decisions such as the one taken by the United States, which was unconceivable just a few months ago.

The trends in the demand for energy at a regional level vary depending on the degree of development. It is forecasted that developing countries will contribute with approximately 74% of the increase in the global demand for primary energy between 2005 and 2030.

Graph 1.1: Demand for primary energy by regions.



The forecasts for electricity demand until 2030 are similar to those for primary energy:

Table 1.2: Forecasts for electricity generation at world scale (TWh)

Regions	2005	2015	2030	2006-2030*
OECD	8.948	10.667	12.828	1,5%
North America	4.406	5.227	6.390	1,5%
Europe	2.957	3.467	4.182	1,4%
Pacific	1.585	1.973	2.257	1,4%
Economies in transition	1.099	1.381	1.729	1,8%
Russia	647	792	968	1,6%
Developing Countries	4.969	9.230	15.180	4,6%
China	2.033	4.409	7.100	5,1%
India	478	950	2.104	6,1%
Other Assian Countries	766	1.306	1.927	3,8%
Middle East	501	779	1.228	3,6%
Africa	456	669	1.122	3,7%
Latin America	734	1.116	1.700	3,4%
World	15.016	21.278	29.737	2,8%

* Average Annual Growth Rate

Developed countries once again show a moderate and homogeneous growth while economies in transition foresee an important growth which could be mirrored by other developing countries catching that growth train depending on political and economic circumstances which are hard to forecast. In any case, the estimated power required is twice what is currently installed in the world.

1.2.2 Exhaustion of conventional resources

Según la Agencia Internacional de la Energía, la demanda energética se incrementará en un 60% hasta 2030, y pare este incremento de la demanda las fuentes de energía convencionales serán insuficientes para satisfacer las necesidades de consumo mundial.

Table 1.3: Proven energy fuel reserves

Forecasts established in 2007			
Type	Demand MMTEP	%	Ratio: Reserves / Production Years (1)
Oil	3.767	39.3	40
Natural Gas	2.420	25.3	63
Carbon	2.778	28.9	147
Nuclear Energy	624	6.5	70- 80 (2)
Total	**9.589**	**100**	
Source: BP Statistical Review of World Energy 2007			
(1) Duration in years of proven reserves according to current production rates (2) Uranium			

Carbon appears as the only source of supply available beyond the 21st Century but, in its current use, it involves the unacceptable generation of greenhouse gases. Thus, a great effort in terms of technological development is being made regarding capturing and storing CO_2 and gasification processes.

As for nuclear energy, it will depend on possible changes in the policies of developed countries which have currently paralysed their implementation plans. If they resumed or extended them, time expectancy would logically be reduced.

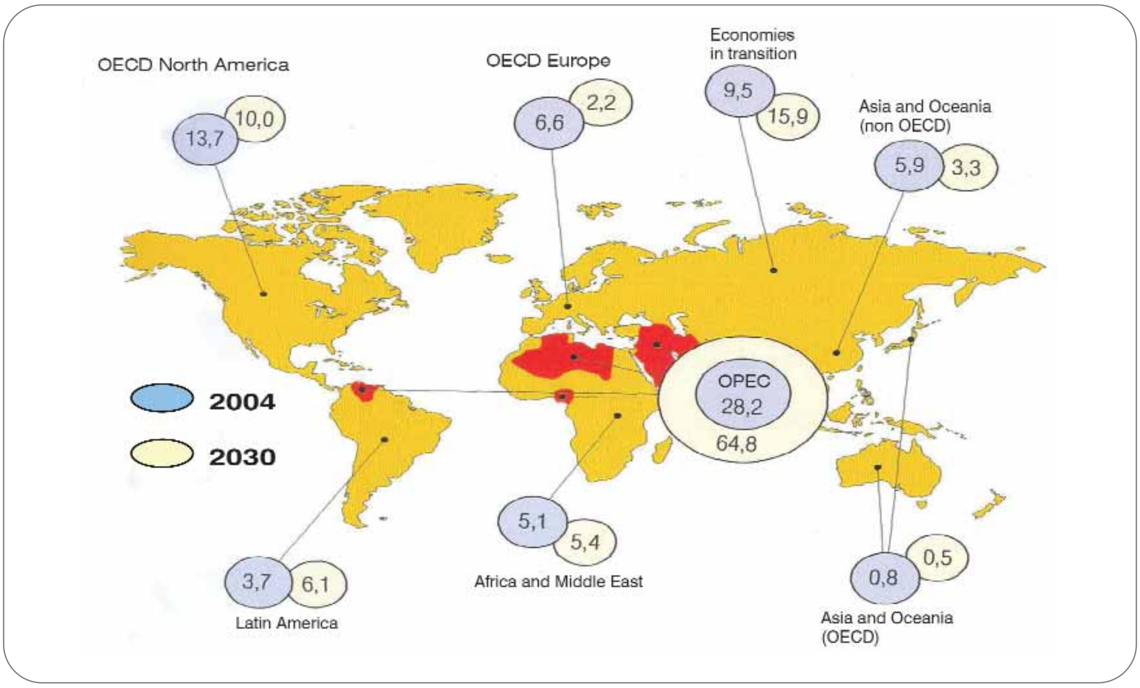
The spectacular growth in gas consumption and the huge infrastructures that have been built and planned all have a limited future.

1.2.3 Concentration

Together with the problem of limited resources, we must bear in mind the important regional concentration of supply sources. This scenario is not expected to change substantially in the next few years. Growing concern with the preservation of the environment has recently made the new President of the United States cancel planned oil prospecting on the coast of the country, particularly on the coast of Alaska.

OPEC countries, which currently hold 33% of oil resources, will hold 60% in 2030.

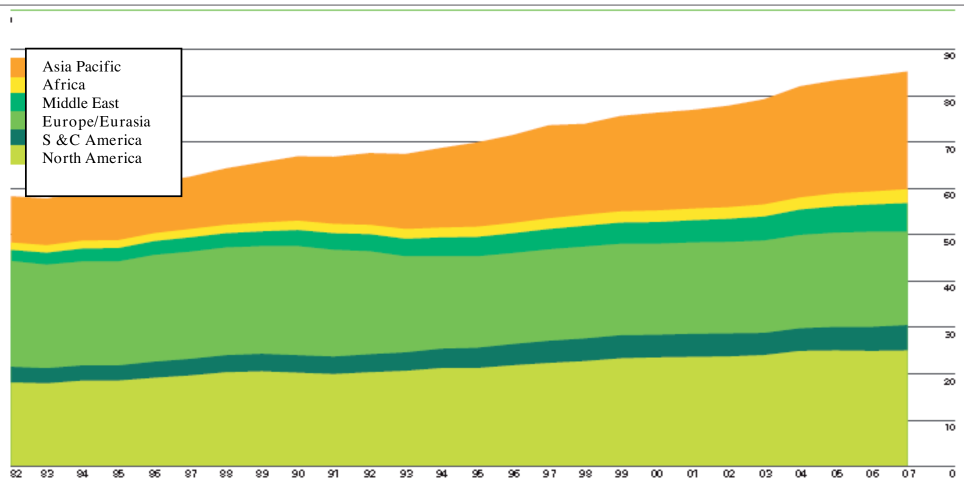
Graph 1.2: Regional concentration of oil resources 2004 and 2030



1.2.4 Dependency and reliable supply

This situation directly generates an energy supply problem for Europe and other developed regions, which is aggravated by the instability of oil prices, the geographical concentration of resources and incidences in the supply of gas.

Graph 1.3: Oil consumption by regions



Source: BP Statistical Review of World Energy

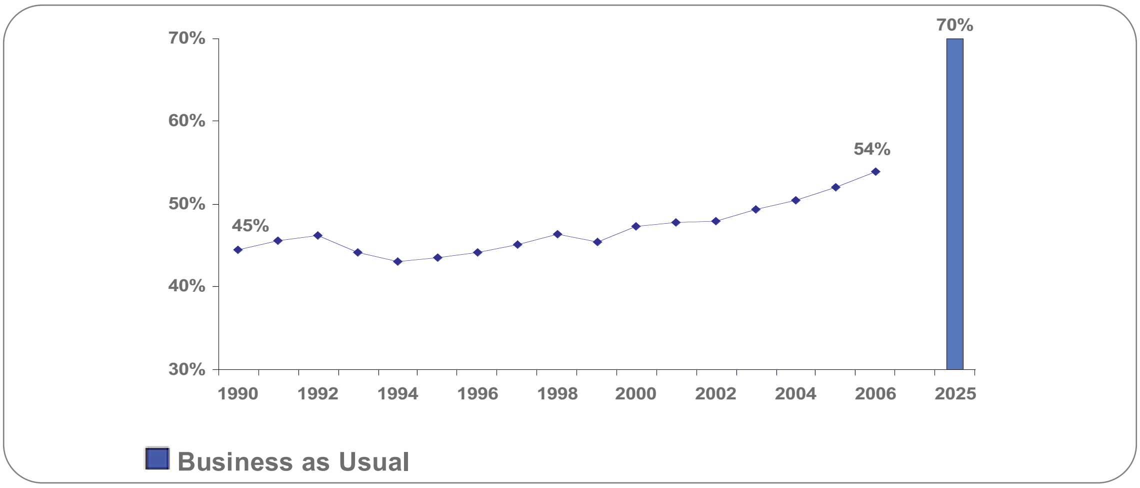
In Europe and other developed countries, the energy supply is problematic and this is aggravated by the instability of oil prices, the geographical concentration of resources and incidences in the supply of gas.

Table 1.4: Energy dependency of OECD countries.

Europe	OECD	USA	Spain	
2007	2007	2007	1986	2008
54%	32%	28%	64%	82%

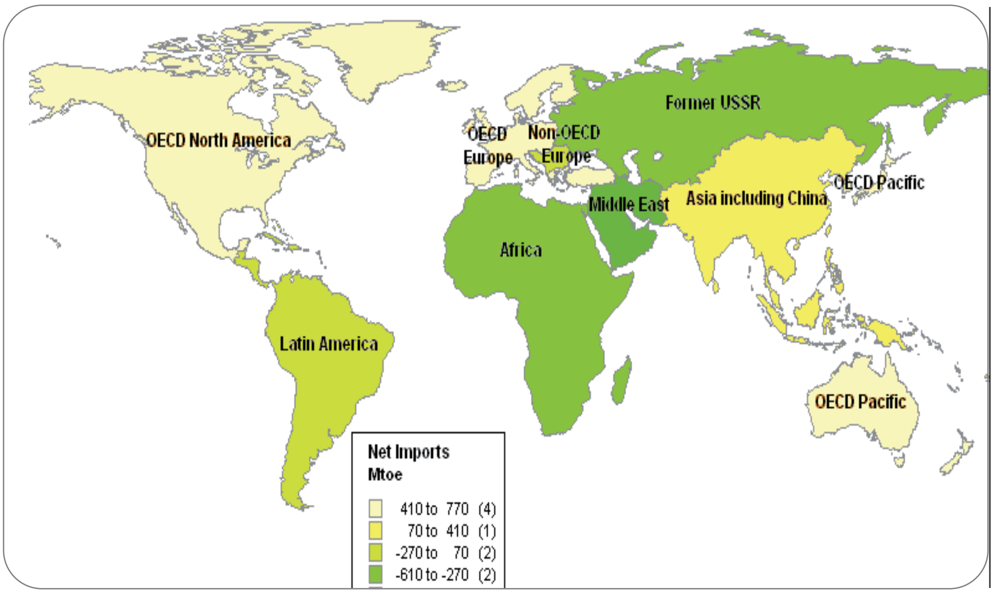
In our country, the dependency ratio has grown significantly given the increase in demand experienced in the last few years due to the shortage of national resources. In Europe, forecasts show the same trend.

Graph 1.4: UE 25 Dependency level



According to the following map, the geographical areas with a greater level of energy dependency are United States, Japan, Australia and Europe.

Graph 1.5: Net energy imports in Mtoe



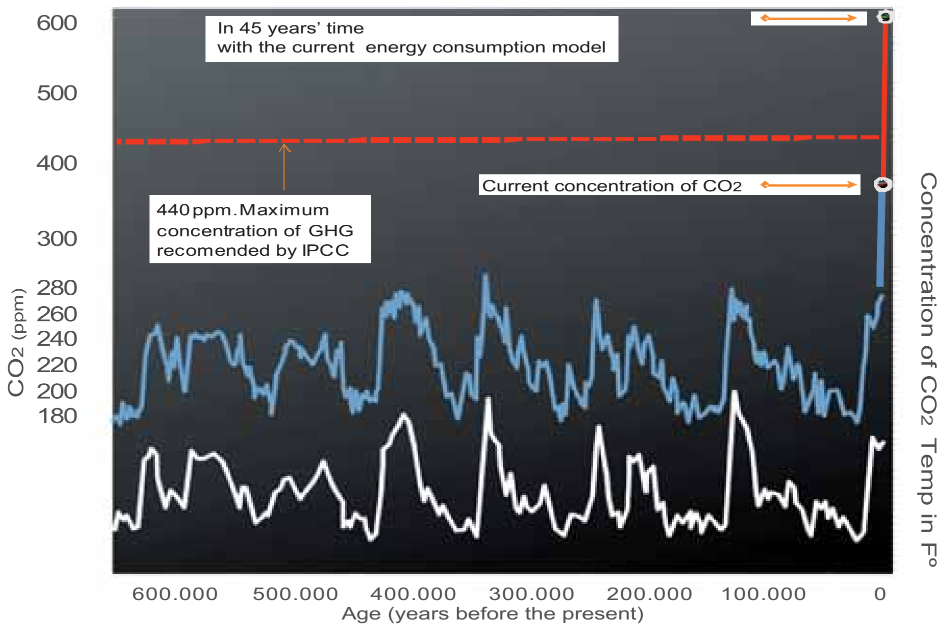
1.2.5 Deterioration of the Environment

Perhaps one of the fundamental factors motivating the new energy model is the environment and, more specifically, the fact that the international scientific community has proved, with unprecedented consensus, the negative consequences that greenhouse gases produced by human activity have on world climate. So-called climate change and its social and economic consequences, set forth in numerous documents, such as the R. Stern report, has generated a gradual and growing trend towards slowing down, if not stopping, this almost inexorable process.

The Nobel Prize jointly awarded to Al Gore and the scientists of IPCC has raised concern in society in general, which now ranks this problem as one of its greater worries, together with unemployment and international terrorism.

At the current pace, the concentration of greenhouse gases (GHG) will exceed the maximum limit of 440 parts per million recommended by the Intergovernmental Panel on Climate Change. The current concentration of GHG exceeds the average of the last 600 thousand years.

Graph 1.6: Concentration of Greenhouse Gases



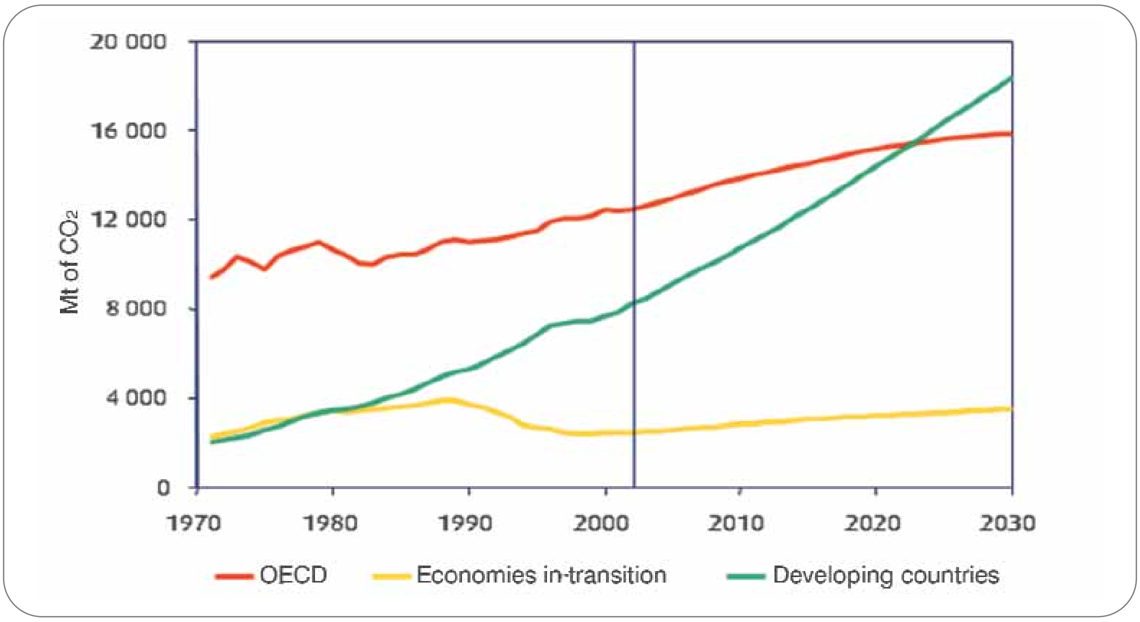
Source: Intergovernmental Panel on Climate Change

Despite the proliferation of currents which deny climate change or its anthropogenic character, the scientific community and most large countries have not only accepted this fact, but have even started to implement corrective measures to bring down the volume of emissions, promoting energy saving and alternative sources of generation.

The present economic crisis has significantly affected the price of the tonne of CO_2, something that, according to experts, will become a decisive factor in establishing real economic references for the different sources of generation.

In line with the anticipated scenarios for energy demand, it is developing countries that will contribute most of the increase in the concentration of GHG in the Earth's atmosphere in the next few years.

Graph 1.7: Forecast of greenhouse gas emissions



1.2.6 Social Inequality

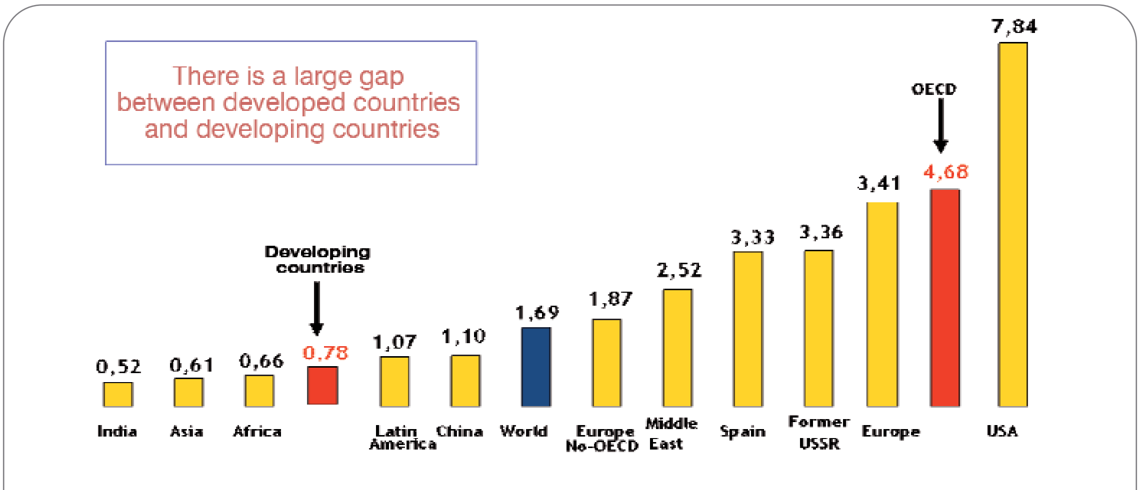
The binomial between energy consumption and development is solid. That is why there is no economic or social development where there is no energy supply and, logically, in undeveloped societies, per capita consumption is much lower than in advanced societies. In any case, the paradox exists that, in certain economies in transition, with high levels of industrial growth, social inequality together with large populations, give low figures of per capita consumption.

This situation keeps widening the gap of social inequality between north and south and, likewise, it does not allow for access to electricity in developing countries to improve.

On the other hand, comparing the effort made in some regions such as Europe with, so far, unfortunate United States policies, produces figures which could be considered outrageous. A United States citizen uses twice as much as a European citizen, with a very similar standard of living. This shows that the margin for improvement that can be achieved by applying energy saving and efficiency measures is great and that the United States could save hugely on energy consumption and, consequently, on money and emissions. In Europe a lot still remains to be done too.

The following graph is very illustrativeof this.

Graph 1.8: Per capita energy demand consumption.



Fuente: IEA. Key World Energy Statistics 2005

In the following table we can see detailed data that reveals this imbalance.

Table 1.5: Access to electricity 2008

Regions	Population	Population with electricity	Population without electricity	Rate of electrification	Rate of urban electrification	Rate of rural electrification
	millions	millions	millions	%	%	%
Africa	831	295	536	35,5	62,4	19,0
Asia (developing)	3.255	2.236	1.019	68,7	86,7	59,3
Latin America	428	382	46	89,2	97,7	61,4
Middle East	173	158	15	91,8	99,1	77,6
Developing countries	4.687	3.071	1.616	65,5	85,3	52,4
Econs. in transition and OECD	1.492	1.484	8	99,5	100,0	98,2
World	6.179	4.555	1.624	73,7	90,7	58,2

Source: International Energy Agency, World Energy Outlook 2008

If the 1,624 million people that do not have access to electricity today could obtain access with an average level of consumption, that is, far from our standards, and with current sources, the forecast tables for raw materials would change dramatically.

That is, the current model, even without an environmental problem, would not be able to supply energy to all the inhabitants on the planet. Not even if the use of nuclear energy became widespread, or we forgot about the problems relating to safety, waste and price.

If our intention is to put an end to the enormous imbalances in society, health, education, labor and welfare that exist between consuming countries and those which have the resources, with only very few exceptions, it is simply not feasible.

All in all, the energy situation in the world is the consequence of a model which, with very slight qualifications, has been built only in developed countries and which has generated two important consequences. First of all, it is no longer applicable in these countries because of the reasons that have already been explained: supply is not reliable, it is not environmentally sustainable, etc. Secondly, it prevents developing countries from having access to the resources controlled by wealthy countries and, on the other hand, it is unfeasible in the mid-term for emerging countries.

The model based on carbon, gas and oil combustion and which has built its electricity systems based on large production and transformation plants and electricity line networks is too costly and inefficient and it is producing irreversible damage to the environment.

The centralised production model in which points of consumption act as mere passive objects has to be substituted, step by step, by a system in which we can obtain maximum consumption efficiency, thanks to the conversion of buildings, factories and outlets into energy management points, using all existing technology for this objective and also turning them into energy generation centers which will enable us to achieve a neutral energy balance.

1.3 A new model for the future

Therefore, the current model is based on the use of fossil fuels and on a centralised management of energy which is unsustainable at world scale.

According to the prestigious and influential New York Times columnist, Thomas L. Friedman, the following United States President will have to lead the E.T. (energy technology) revolution.

This revolution will be based on a new energy model, based on the use of renewable energies for a new "renewable" industrial sector which will become the new engine for development, capable of creating wealth and work, based on sun modules, wind turbines, bio-fuels, etc. In other words, Friedman suggests that, "We need to get back to making stuff based on real engineering, not just financial engineering."

In this sense, the European Union is well situated in terms of its views and knowledge concerning the industrial and technological sector, and also given the dynamics of the solid policies it can generate and which place it in an optimum position to lead a global change towards a low-carbon economy.

It is expected that this change will bring about collateral effects including prosperity, wealth and employment creation and also progress towards an economy based on knowledge and sustainable development.

Likewise, as has already been pointed out, developing countries will play an essential role in the face of this new challenge. In these regions, access to electricity, modernisation of the electricity system and, in many cases, energy independence, are strategic pillars for the future development of their countries and the well-being of their population.

During the last ASEM[3] meeting, the economist Nicholas Stern, author of the report under the same title on the economic impact of Climate Change, said in reference to the current financial crisis, "The lesson that we can draw from this recession, is that you can boost demand in the best way possible by focusing on low carbon growth in future."

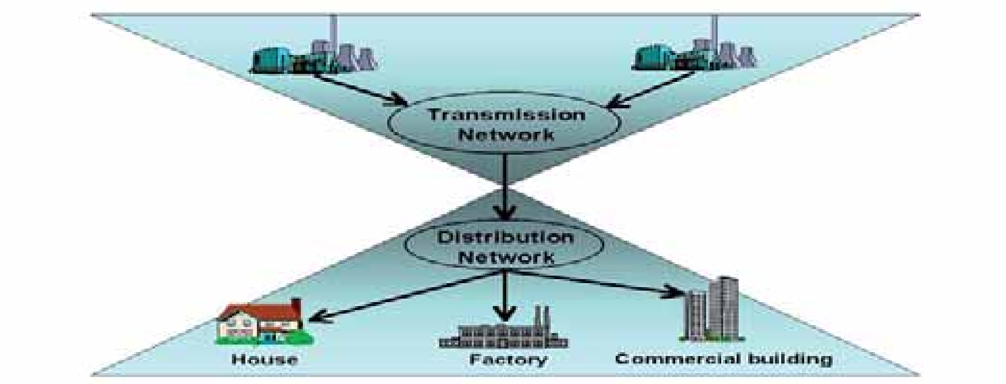
3 The Asia-Europe Meeting (ASEM) is a multilateral meeting between Asia and Europe which has been held for the last 12 years. Its aim is to reinforce interaction and understanding between these two regions of the world by establishing dialogue. This initiative is promoted by the European Commission.

According to the International Energy Agency itself, its Reference scenario is economically, environmentally and socially unfeasible and unsustainable.

In a radical u-turn in its traditional approach, the IEA has called on OECD countries in reference to the current energy model and the need for it to evolve in order to face "the challenge of all nations embarking in a transition towards more reliable energy systems, with lower carbon emission levels, not to the detriment of economic and social development."

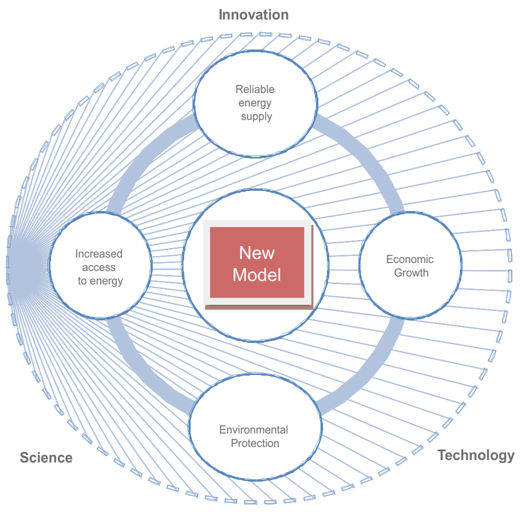
The European Union has become the political leader in this change, taking up renewable energies as the standard bearers in this evolution, based upon a society of knowledge and solidarity, both amongst European citizens and between Europe and the rest of the world.

Graph 1.9: Current Energy Model: centralised, inefficient, unsustainable



This graph shows very simply, succinctly and conceptually the current electricity system, which we consider to be exhausted. What should the new model be like?

Graph 1.10: The new Energy Model



The new model is based on the combination and interaction of three basic vectors: science, innovation and technology, providing the keys for an energy system capable of responding to our society's needs in this context:

- Increased access to energy
- Economic growth
- Reliable supply
- Environmental protection

The electricity system must be decentralised and electricity must be distributed with the necessary levels of storage and hybridisation to substantially improve global performance and maintain a reliable supply. This can be achieved with renewable energies (solar, wind, hydraulic and biomass) and cogeneration wherever it is impossible to cover supply with renewable energies.

The transport system must be substantially supported by electrical vehicles of all sorts (trains and road transport for both passengers and freight) and by internal combustion vehicles working on bio-fuels. The percentage of fossil-fuels should be lower all the time and performance should be maximised. Electrical vehicles must be part of the storage section of the electricity system and, thus, would be the interface between the two subsystems.

The new model involves developing and applying all technological, financial and political solutions available in order to ensure sustainable development for the present and future generations.

Transforming reality in order to build a sustainable economic model will imply a third industrial revolution such as is described by United States economist Jeremy Rifkin. This revolution would take us to a new era of "Distributed Capitalism" and would help us face the triple challenge of economic growth, energy independence and climate change and would change our relationship with energy as significantly as the first and second revolutions did in the 19th and 20th Centuries. According to Rifkin, this development is based upon four pillars, the first of which is renewable energy. The technological advances of past years have already shown us the potential of this pillar. The second pillar would be housing and office buildings working as power plants as well, although in this case there are still too few examples. Hydrogen as a third pillar of this model contributes the possibility of storing renewable energy and could therefore guarantee universal availability of a stable and effective supply. Finally, the fourth pillar would be intelligent distribution networks which would allow for measured use, perfectly adapted to demand. These networks could work in the future in order to allow each person to produce and share their green electricity with the rest of the economic system.

We can see this in an image. Even if the picture looks somewhat simple, it includes essential elements which must conceptually shape the new model we are aspiring to for 2050

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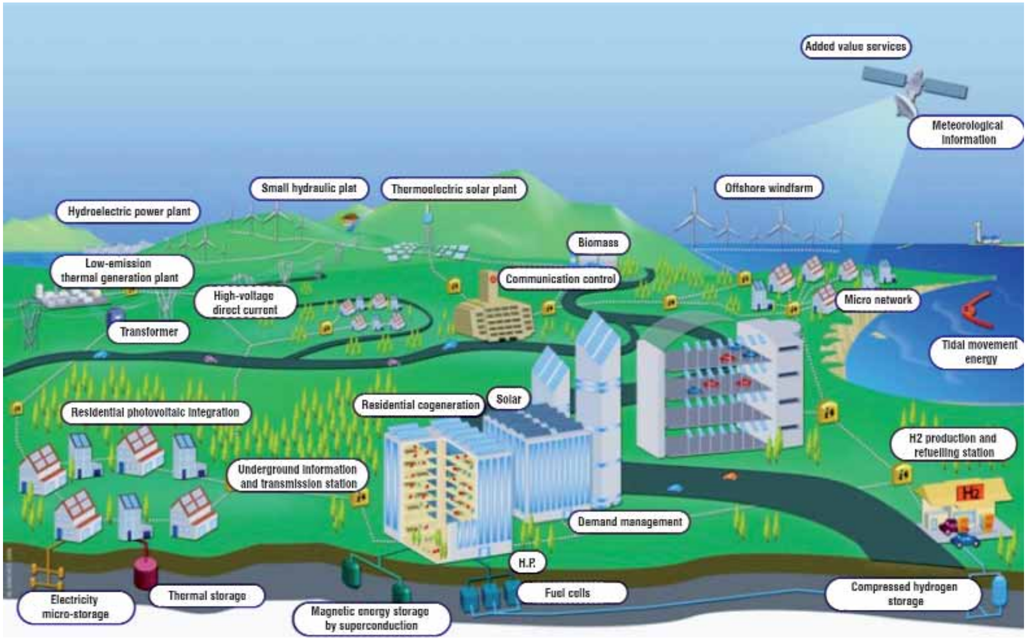
Graph 1.11: Essential elements in the new Energy Model



- Mass usage of renewable energy sources
- Bringing generation closer to the demand
- Bioclimatic construction with a neutral energy balance
- Intelligent networks with interactive management of demand
- Management of surface transport mobility with zero emissions
- Accumulation and storage of energy
- Clean use of fossil fuels

This structure, far from being utopian, is already viable with the implementation of the appropriate policies.

1.4 Roadmap to 2050

PThat is why this chapter finishes with a suggested roadmap in order to attain this model. The Report includes recommendations for public powers and citizens to lead this effort. If Spain takes such a position in this process and joins its modest experience with that of countries such as the USA, the new global model will soon become a reality.

Spain and the whole world need an energy system based on the idea of a "sustainable economy" that is, "a model that can supply for present needs without compromising the possibilities of future generations to satisfy their own needs." This system must be respectful with the environment, based 100% on renewable sources of energy in the long term and it must have the complicity of all involved actors: consumers, managers, administrators, companies, researchers, educational system, etc.

Users and consumers:

The use of final energy (of natural or commercial origin) must be optimised in the sense of minimising the need for electricity and fuels at the source of demand, which is households, services (hotels, offices, hospitals, etc.), industries, transport, agriculture, fishing and, in fact, in all consumption sectors.

In order to reach that minimum level, the following conditions must be fulfilled:

a. Private, commercial and industrial consumers, as well as public services, must be aware of their importance and of the central role they play in achieving these aims.

b. Requirements for citizen wellbeing and daily activities must be met: light, transport, food preservation, heating or cooling systems etc. The first resource that can be counted on is natural energies that can be used efficiently. For example, a high percentage of sunlight can be used during the day if the buildings are correctly designed. Water for everyday use can be heated up by means of solar installations, etc.

c. Intelligent construction (bioclimatic and energetically responsible) must maximise the passive use of natural resources, rather than using conventional energy resources that are not efficient.

d. The use of intermediate energies (electricity and fuels) must be made efficient, by means of devices which are already in the market, and reasonable, avoiding unnecessary waste (leaving lights and TV on when nobody is using them, driving when it is possible to go on foot or by bicycle, setting air conditioners too low or heating too high, etc.)

e. Whenever it is indispensable to use intermediate energies, the application of energy efficiency and saving systems in industrial, commercial and domestic processes will make energy products cheaper by minimising the necessary amount, providing more competitiveness to the business fabric and improving the quality of life of the citizenship.

f. Making the most of space to contribute to the general energy system by generating intermediate energy (particularly electricity and heat) in order to feed direct on-site consumption and the general electricity network.

g. A new "mobility" model must include better travelling habits and promote the technological development of transport and of the network in order to gradually eliminate dependency on fossil fuels and the corresponding emissions of GHG.

h. Property owner associations and neighbourhood associations, industry, farmers, fishermen and public services must become actively involved with the change process towards a new system.

i. In the search for a sustainable energy system, the life habits of citizens must be taken into account and not modified capriciously. Sleeping in the daytime and working or having fun at night increases waste, so habits must be adapted to natural conditions rather than changing customs when this change will involve a waste of artificial energy.

Energy system operators:

The energy system as it is today (electricity generation and fuel extraction), transport of the commercial products (electricity and fuel networks), distribution (electricity substations and electricity lines, petrol stations and gas distribution), sale of these energy products and of consumption devices (fridges, air conditioners, boilers, washing machines, dishwashers, etc.) and their upkeep must all be optimised and complemented with new agents and devices based on renewable energies, increasing their number by turning many final consumers into active agents rather than just passive consumers, as they have been in the conventional energy system.

In order to contribute to the improvement of the general energy system and participate in the achievement of the aim established above, these actors must:

a. Gradually substitute the large units of centralised electricity generation that use fossil fuels and uranium with others that are better suited for the level of consumption in the area, in terms of size and of geographical location, working according to the concept of cogeneration as much as possible and becoming integrated with renewable sources in accordance with the technological evolution of all systems and promoting a general cost reduction of all devices and services.

b. Decentralise the generation, transport and distribution structure of intermediate energies (electricity and fuels), bringing consumption and generation as close as possible in space and time.

c. Develop intelligent and well controlled networks that can make the most of the energy generated, avoid or cut down leaks as much as possible and guarantee supply thanks to the development and implementation of storage and accumulation technologies.

d. Cut down the carbon component in the case of fuels used in the transport sector for both freight and passengers, moving on to a more efficient system integrated with the electricity system, with a transition period during which fossil fuels will be gradually substituted with bio-fuels and electricity.

e. Promote the use of renewable energies and efficient systems, which will minimise the transport of energy and better fit its distribution to the real consumption situation

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Companies:

It is very important, in order to attain the proposed aim, that energy companies change their behaviour substantially and understand the significant role that they play. Many new companies will be created, probably smaller and more scattered, including many consumers which will also become generators.

The companies with greater involvement in the implementation of the new model are located mainly on one of the two extremes of the system: generation and consumption. The change that needs to take place includes the following aspects:

a. Investing in R&D&I and improving their plants to produce intermediate energies more competitively and efficiently all the time. Without forgetting about the maximum possible use of renewable energies or about minimising pollution and the inevitable impact of the whole process.

b. Manufacturers of renewable energies: wind turbines, photovoltaic modules, thermoelectric solar plants, offshore wind power generators etc. must also promote R&D&I in order to accelerate their implementation process in the system and the improvement of their performance.

c. Engineering and laboratories working on the design of new technological concepts aimed at improving network management must move in the same direction, cutting down pollution, impacts and costs.

d. Manufacturers of machinery, consumer goods, household devices (appliances, air conditioning and audiovisual equipment, etc.) which, in general, require electricity and/or fuels, must evolve towards lower energy requirements, that is, they must be energetically optimise their products.

e. High consumption production systems must be substituted with more efficient systems in factories and along the whole process.

f. All products that fail to comply with energy regulations must be eliminated from the market and more efficient products must be promoted.

Administrations and state bodies:

Political decision-makers and administrative technicians managing the energy system bear the greatest responsibility for the whole change and improvement process, from the corresponding Ministry to the municipal and provincial delegations involved (urban planning, environment, services, etc.) including the corresponding departments of the regional Autonomous Communities, which have wide competences regarding energy issues. It is essential for all of these agents to be committed in order to set in motion the mechanisms for change and demand their fulfilment from all other agents.

Below is a list of some of the competences and duties which must be demanded:

a. From Parliament and the Central Government to Town Councils, including Autonomous Communities and Provincial Governments, they must all promote training and information mechanisms for individual citizens, companies and the whole of society, communicating the messages that will bring about a change in habits regarding energy consumption.

b. Laws, regulations and mechanisms that favour and reward energy saving and efficiency and that penalise waste must be introduced.

c. Mechanisms must be created in order to efficiently promote and facilitate the use of renewable energies. Positive behaviours must be facilitated and rewarded and negative behaviours must be sanctioned.

d. Institutions and companies that control and regulate energy services must be promoted in all sectors of the energy system, particularly in consumption sectors.

e. They must plan the progressive implementation of the new system, set out aims and facilitate development and implementation of infrastructures and usage procedures.

f. They must specifically obtain the commitment from the large agents in the energy sector by establishing compulsory milestones, rewarding those who contribute to the attainment of the basic established aim and sanctioning those who hinder it.

Educational system:

It must be remembered that the best way of attaining any aim in this complex society is by means of conviction and education, from initial levels to the most highly qualified. Therefore, the educational system must play an essential role in attaining the aim presented above.

a. Primary and secondary schools and higher education centers must become actively involved with training to favour learning about the energy system and the better use of energy. In this way, new generations will have assimilated the basic concepts involved.

b. They must also promote interest towards research and development regarding energy issues.

c. Universities must design specific programs in order to feed the sector with qualified professionals, which are the essential foundations for a sustainable energy system.

d. Research and development must be connected to companies, administrations and even users and consumption processes.

This roadmap sketches a way towards a fully sustainable model for Spain. The following chapters describe in detail the features of different aspects of this model and show their technological and economic feasibility.

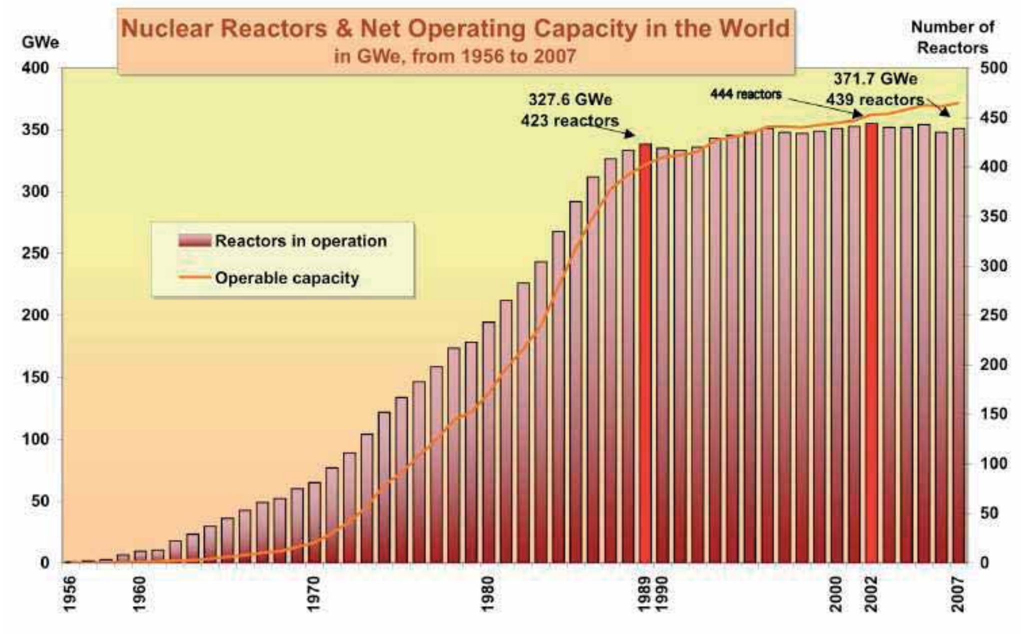
2 Nuclear Energy is not the Solution

2.1 The uncertain future of Nuclear Energy [1]

2.1.1 The troubled past and uncertain future of nuclear energy

The history of the first investment cycle in nuclear generated electricity is reflected in Figure 2.1.1. As can be seen in the Figure, the number of operating reactors and their power generating capacity suddenly stalled in the early 1990's, and has since then remained virtually stable, with slight increases in generation capacity as a result of the replacement of old reactors for new ones and efficiency improvements in existing plants

Figure 2.1.1 Trends in Operational Nuclear Generating Capacity in the World



Source: The World Nuclear Industry Status Report 2007[2]

At the end of 2007, there were 439 units operating in the world (five units less than at the historical peak in 2002), which total 371.7 GWe of capacity. The average age of operating nuclear power plants is 23 years, nearly half their operational lifetime. The capacity of the global fleet increased annually between the years 2004 and

1 This chapter was written by Marcel Coderch Collell, member of the Sustainable Developments Advisory Board to the Catalan Regional Government

2 *The World Nuclear Industry Status Report 2007*, The Greens/European Free Alliance, enero 2008 (http://www.greens-efa.org/cms/topics/dokbin/206/206749.pdf)

2007 by about two GWe, owing to uprating of capacity in existing plants, rather than new builds.[3] This leaves nuclear power with a global share of roughly 1.5% of the annual increase, since the annual increase in all electricity generating capacity is about 135 GWe. This means that the roughly 14% share of nuclear generated electricity in 2008 will decline year over year unless a significant new building program is started. In fact, owing to a series of accidents in 2007, the generation of nuclear electricity in the world dropped by 1.9%, in absolute terms, [4] and 8.3% in Spain.[5] It currently represents roughly 6% of commercial primary energy, and 2%-3% of final energy consumption, that is less than hydropower's share. The developments of the last two years have not improved this scenario since, although new building plans have been announced, few new reactors have come on line. In fact, in 2008, for the first time in nuclear power history, no new reactor was connected to the grid, hence, nuclear capacity has remained unchanged since 2009, although three operating reactors have been shutdown.[6]

In light of an aging fleet that has surpassed half the average lifetime, with virtually unchanged net generating capacity, and is, therefore, incapable of meeting increasing demand, the nuclear industry is in danger of slowly but surely disappearing unless it carries out a drastic makeover. Figure 2.1.2 shows a projection of future trends in the global nuclear fleet, considering an average lifetime of 40 years per reactor, and including the reactors under construction in 2007.

As can be seen in this Figure, more than half of the existing units would have to be shut down and decommissioned prior to 2025. In other words, given the existing licensing and construction schedules, unless a far-reaching building program is started soon, nuclear energy will play a marginal role in the energy mix, involving significant liabilities from decommissioning of nuclear plants and management of the waste accumulated during their operation.[7] In light of this calendar, there can be suspicion that license extensions for certain US nuclear plants beyond 40 years has more to do with the fact that it is materially impossible to replace a nuclear fleet that represents quarter of the world total than other considerations, and this question will be examined below.

3 *World Energy Outlook 2006*, Agencia Internacional de la Energía. (http://www.worldenergyoutlook.org/2006.asp)

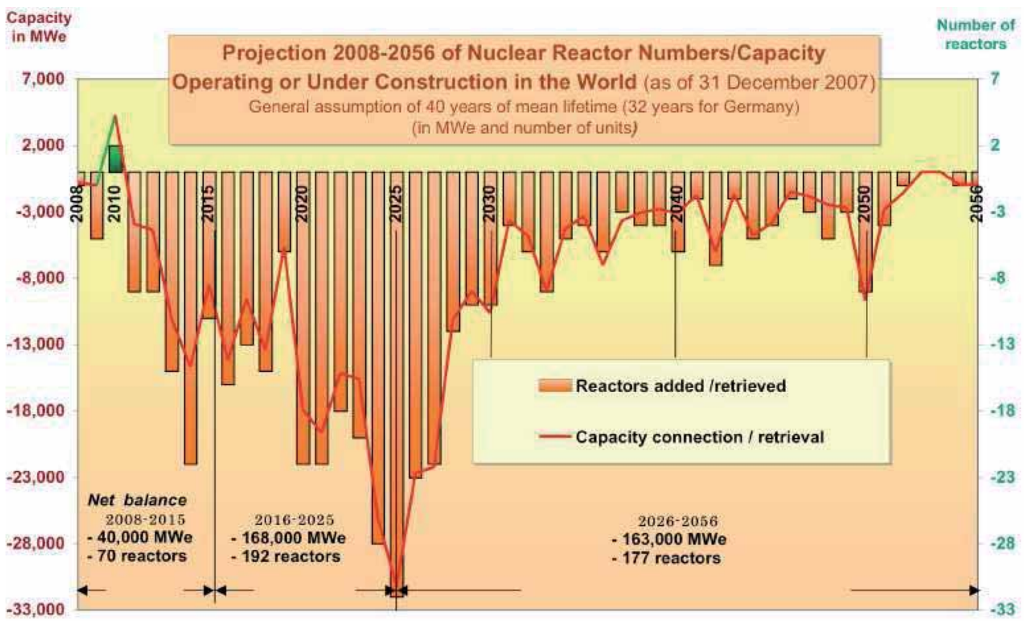
4 *Nuclear generation drops 1,9% in 2007*, World Nuclear News, 9 de junio de 2008. (http://www.world-nuclear-news.org/)

5 *Resultados y Perspectivas Nucleares 2007*, Foro Nuclear, junio 2008. (http://www.foronuclear.org/pdf/Resultados_perspectivas_nucleares_2007.pdf)

6 *World Nuclear Power Reactors 2007-2009*, World Nuclear Association, febrero 2009. (http://www.world-nuclear.org/info/reactors.html)

7 According to the Nuclear Decommissioning Authority, set up in the United Kingdom for managing British Energy and British Nuclear Fuels liabilities, the estimated cost of decommissioning British nuclear plants and waste recycling facilities is in excess of ?100 billion, with the taxpayer having to foot the bill without any compensation, given that this expenditure had not been provisioned to nuclear generated electricity. Refer, for example, to: £73bn to take nuclear plants out of service, David Hencke, The Guardian, 30 January 2008. (http://www.guardian.co.uk/environment/2008/jan/30/nuclearpower.energy)

Figure 2.1.2. Future Trends in Nuclear Generating Capacity in the World



Source: The World Nuclear Industry Status Report 2007[2]

The nuclear industry and several Western governments have therefore launched a massive PR campaign[8] to rebrand nuclear power as a vital, environmentally sound energy alternative to solve the energy-climate dilemma. According to these sources, this justifies further investments in nuclear plants. For instance, the World Nuclear Association (WNA) has stated that "increasing energy demand, concerns over climate change and dependence on overseas supplies of fossil fuels are coinciding to make the case for nuclear build stronger. Rising gas prices and greenhouse constraints on coal have combined to put nuclear power back on the agenda for projected new capacity in both Europe and North America." [9]

Rising demand for energy, increased fossil fuel prices, greenhouse constraints, and energy independence are the four reasons proffered for justifying the re-opening of the nuclear debate, and for reconsidering the nuclear moratorium that, in one way or another, is still in force in most Western countries. However, two basic issues have been ignored by those who make repeated calls for retaking the nuclear path. Firstly, they omit the reasons for which the first era of nuclear plants was brought to a close, and fail to take into consideration that, even if one was to admit that these have been solved - which they haven't - a quantitative and dynamic analysis of the true potential of nuclear renaissance would show that it would barely contribute to solving the problems mentioned above. These problems are doubtlessly severe and pressing, and call for optimum management of available resources. If we look with care at the issue, the nuclear option not only does not contribute to solve these problems, but rather, could aggravate or, at the very least, delay and hinder the development of more effective solutions.

8 *The nuclear charm offensive*, Jonathan Leake, New Statesman, 23 de mayo de 2005. (http://www.newstatesman.com/200505230004)

9 *The Nuclear Renaissance*, World Nuclear Association. (http://www.world-nuclear.org/info/inf104.html)

2.1.2 The real motives of nuclear decline

If the truth were known, the nuclear industry was not the brainchild of economic and business decisions, but rather political and military determination.[10] This would explain the economic constraints it faced from the outset. C.G. Suits, Vice-President and Director of Research and Development of General Electric, noted in 1950 that "atomic power presents an exceptionally costly and inconvenient means of obtaining energy.... This is expensive power, not cheap power as the public has been led to believe".[11]

Now is not the time to review what happened between the 1960s and the 1980s,[12] nonetheless, it is important to understand the causes of Figure 2.1.1 to dispel misunderstandings. The trend shown in this figure is usually interpreted as the result of high oil prices in 1973, which led to the building of nuclear plants. The momentum slowed down owing to the accidents at Three Mile Island in 1979, and, definitely, after the disaster at Chernobyl in 1986. However, this interpretation overlooks a fundamental aspect: roughly 10 to 12 years will elapse from the moment when the decision to build a nuclear plant is taken to the moment when the plant is operating, and, therefore, the timeline must be shifted backwards more than a decade to determine when the building decisions were taken and when they were halted. What actually happened is illustrated in Figure 2.1.3., which shows the aggregated number of nuclear reactor orders in the US, including cancellations of projects under construction and plant closures between 1953 and 2001.

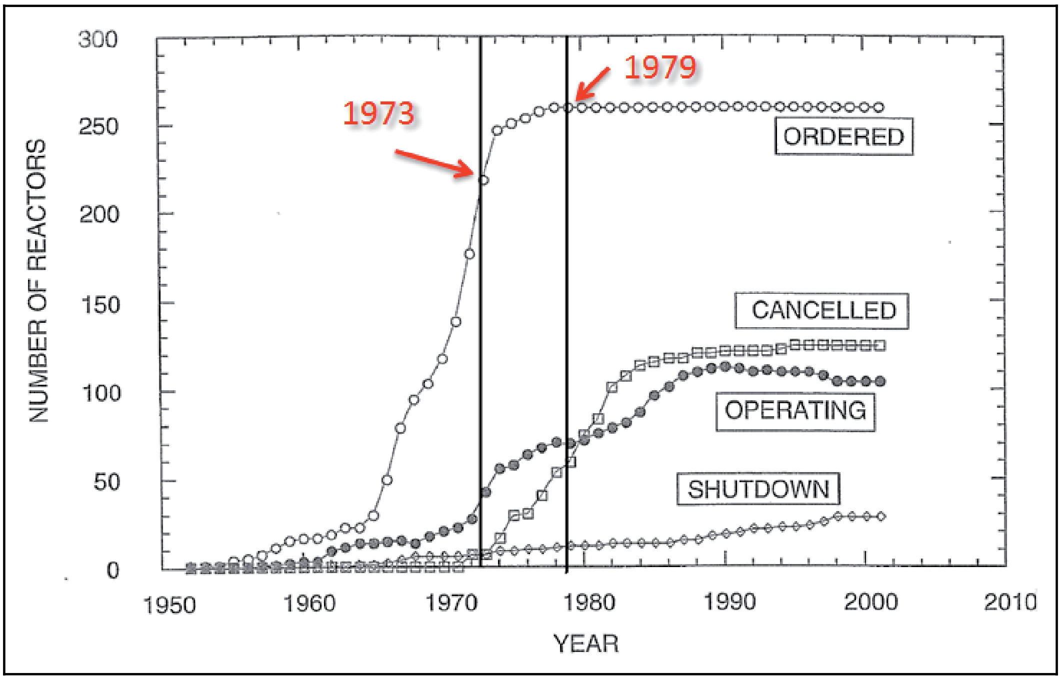
The number of reactor orders in the US increased significantly between 1965 and 1974, but the situation changed suddenly in 1974. Whereas 129 reactor orders were placed between 1971 and 1974, only 13 new orders were placed between 1974 and 1978, and no new order has been placed since 1978 to date. None of the plants commissioned after 1973 have been completed: 124 reactors were cancelled between 1974 and 1984, i.e., more than new plants that have been put into operation. Only 132 of the 259 orders placed and 177 building permits granted have been put into operation. There are only 104 plants still in operation today. It is worth noting that the accident at TMI took place in 1979, and, therefore, it cannot have been the cause of this sharp downward trend.

10 As David E. Lilienthal, the AEC's first chairman, wrote in his journals: "I cannot believe that God would create mankind and give it the capacity to extract the energy in the nucleus of the matter, only to have this knowledge used for destroying this wonderful world, which is God's, not men's handiwork". This statement encapsulates the main motivation for civil development of nuclear energy in the West: the horror of Hiroshima and Nagasaki had to be expunged at any price, especially since the Cold War would require a sharp increase in nuclear weapon production. The only way to ensure military use of nuclear energy without significant public opposition was to publicise and promote the "many advantages" of nuclear energy for civil purposes. This and none other is the origin of all nuclear energy development programs for civilian uses; an origin that explains the economic constraints it faced from the outset.

11 *Power from the Atom – An Appraisal*, C.G. Suits, Nucleonics, Vol. 8, No 2, February 1951. In that same article, C.F. Suits wrote "It is safe to say ... that atomic power is not the means by which man will for the first time emancipate himself economically, whatever that may mean; or forever throw off his mantle of toil, whatever that may mean. Loud guffaws could be heard from some of the laboratories working on this problem if anyone should in an unfortunate moment refer to the atom as the means of throwing off man's mantle of toil. It certainly is not that."

12 Those interested in learning more about this period may refer to *Light Water: How the Nuclear Dream Dissolved*, Irvin C. Bupp & Jean-Claude Derian, Basic Books, 1978; *Nuclear Inc.: The Men and Money Behind Nuclear Energy*, Mark Hertsgaard, Pantheon Books, 1983; and the reference book No 13.

Figure 2.1.3. Trends in nuclear plant orders in the US



Source: David Bodansky, Nuclear Energy: Principles, Practices and Prospects [13]

The causes of this failure were almost exclusively economic,[14] and the sharp drop in electricity demand during the crisis of the 1970s was a very important factor. Whereas demand had increased 7% annually between 1953 and 1973, this growth ceased abruptly in 1974 and dropped 0.4% due to the economic crisis induced by the dramatic increase in oil prices in 1973. Fiscal growth slowed down in 1974, with greater emphasis on energy saving, and, consequently, the annual average growth in energy consumption between 1975 and 2000 dropped to 2.7%. This meant that power utilities had excess capacity under construction or planned. Their first reaction was to suspend the expansion plans, however, this was not sufficient, and they were compelled to cancel multiple projects that were at different phases of development. This adverse economic situation was compounded by the TMI accident in 1979. This firstly entailed the suspension of all licenses and building during one year and, subsequently, under popular pressure, an increase in safety measures, which had a significant impact on costs and construction schedules and, therefore, on cancellation rates. Moreover, the monetary policy adopted to cope with the 1973 recession resulted in significant increases in interest rates, which aggravated the already difficult situation. This resulted in the financial collapse of the electric utilities and the nuclear program in the US and other countries.[15]

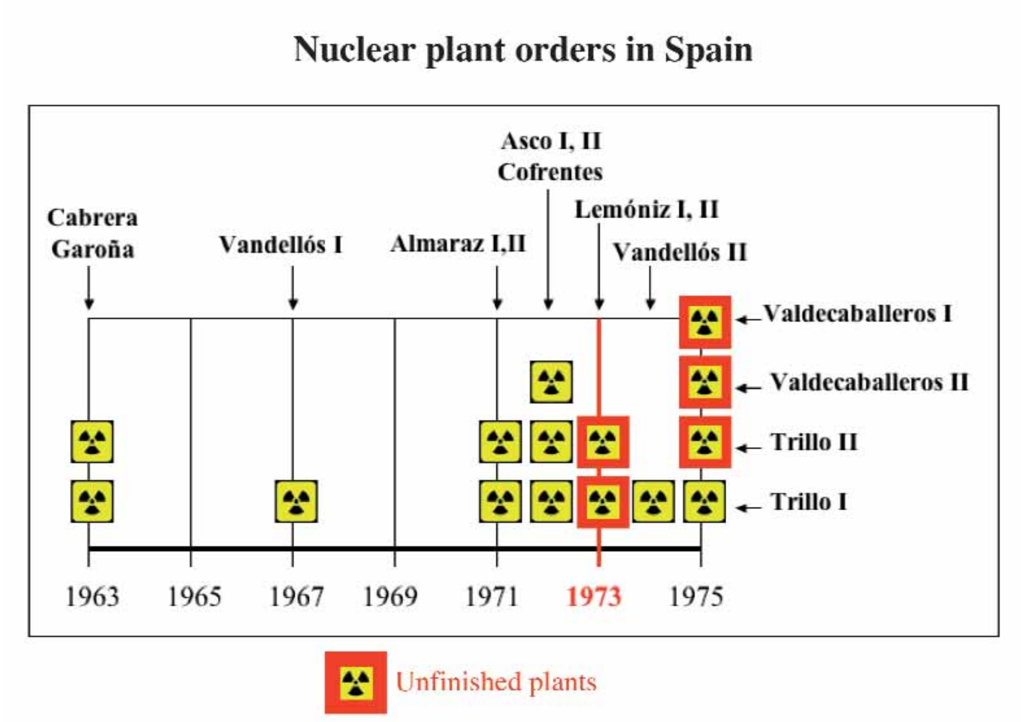
13 *Nuclear Energy: Principles, Practices and Prospects*, 2nd Ed., David Bodansky, Springer, 2004

14 "The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power, with an additional $140 billion to come before the decade is out, and only the blind, or the biased, can now think that the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible", *Nuclear Follies*, James Cook, Forbes, 14 February 1985.

15 The French nuclear program, which did take off after the 1973 oil crisis, warrants a separate mention. Note 21 of the reference document explains the motives behind this program and the difference between the US and France, which has a nationalised structure of electric utilities.

As shown in Figure 2.1.4, something similar occurred in Spain, especially if we take into consideration that Lemoniz was strongly influenced by ETA's terrorism. In the absence of such threats, the two reactors located on the Basque coast, which are virtually completed, would have been put into operation instead of Vandellos II and Trillo I. Therefore, under normal conditions, none of the Spanish reactors that were built after 1973 would have been put into operation, exactly as in the US.

Figure 2.1.4. Trends in nuclear plant orders in Spain



Source: Marcel Coderch and Núria Almirón, El Espejismo Nuclear[16]

The Spanish nuclear moratorium affected five nuclear groups, which were at different stages of completion, for the same reasons as in the US. The situation was further aggravated by the fact that Spanish electric utilities had contracted debt in dollars to finance the building of nuclear plants, and the increase in interest rates was compounded by an adverse evolution of the exchange rate. On the other hand, the loans were guaranteed by the Spanish State, and Felipe Gonzalez's first administration chose to assume these investments and shift the

16 *El Espejismo Nuclear: Por qué la energía nuclear no es la solución sino parte del problema*, Marcel Coderch y Núria Almiron, Los Libros del Lince, 2008

payment of bad nuclear investments to future electricity rates over a twenty-five year period. These investments had already been included in the National Electricity Scheme approved by successive governments of the Transition.[17]

Strictly speaking, Spain has never introduced a ban on building new nuclear plants, beyond the nuclear moratorium established for the five units at Lemoniz I and II, Valdecaballeros I and II, and Trillo II. The existing Law 54/1997 on the Electricity Sector clears any doubt on the subject when it states that "regarding electricity generation, the right to set up business is recognised, and shall organise its functions under the principle of free competition". Therefore, there is no ban or moratorium in place in Spain, at least as and from 1997.

In any case, nuclear power was a global financial failure in the mid-1970s, and was also adversely affected by the accidents at TMI (1979) and Chernobyl (1986). These accidents corroborated the view of people who criticised from the outset the hazardousness of nuclear power, and contributed towards the prevailing public opinion contrary to its reactivation.[18] In some respects, the history of nuclear power over the last four decades can be summarised as a shift from too cheap to meter[19] to too expensive to matter, and too unpopular to insist.

2.1.3 The Global Future of Nuclear Power: An MIT Study

In 2003, the Massachusetts Institute of Technology (MIT) brought together a select, interdisciplinary faculty group to study the future of nuclear power, and the merit of retaining this option in the future as an electricity generation technology. This report, which at present is still the most comprehensive and far-reaching, quantitative and qualitative analysis on the future of nuclear power,[20] is based on the premise that nuclear power may be an option in reducing greenhouse emissions, but that "at present, however, this is unlikely owing to nuclear power stagnation and decline". The study analyzes the assumptions must hold true to preserve nuclear power as an important option for reducing greenhouse emissions, whilst contributing to meeting increasing demand for electricity.

The MIT experts concluded that to preserve the nuclear option for the future requires overcoming four challenges from its earliest days — costs, safety, proliferation, and wastes - to which we could perhaps add public acceptance. These challenges will escalate if a significant number of new nuclear generating plants are

17 To this effect, the observation by the former Minister of Industry, Juan Manual Eguiagaray, merits being quoted: "It is recognised that during the democratic transition the public sector had to come to the financial rescue of the Spanish electric utilities, who had embarked on an overambitious investment program, stemming from frenzied planning efforts, that were clearly at odds with the established requirements of Spain's electricity demands. The emphasis these plans placed on nuclear power led to the building of more nuclear units than those reasonably required, which, for financial as opposed to other reasons, resulted in the so-called nuclear moratorium in 1982. Consumers paid for the cost of suspended construction and financial recovery of the enterprises during many years, through a surcharge on every customer's electricity bill." Reflexiones sobre la incertidumbre energética, Juan Manuel Eguiagaray, Cuadernos de la Energía, nº 21, June 2008, Club Español de la Energía. (http://www.enerclub.es/es/frontNotebookAction.do?action=viewCategory&id=40&publicationID=1000047100)

Carlos Solchaga, the Minister of Industry in Felipe Gonzalez's first administration, stated "on May 6th 1983, the PSOE administration signed the Memorandum of Understanding of Electric Utilities ... and decided that the 50% increase in electricity rates is to be utilized for the financial recovery of the sector, which was simply bankrupt", El Siglo, 25 September 2005.

18 For instance, refer to *Attitudes Toward Energy*, Eurobarometer 2006, European Commission. (http://ec.europa.eu/public_opinion/archives/ebs/ebs_247_en.pdf)

Nonetheless, recent surveys seem to show that, in certain countries, these negative attitudes are in decline, probably owing to the pressure from the media in recent years. In Finland, where the first shift in public opinion to place, recent surveys interestingly show that those who are against building new reactors are once again majority (53%) versus those who support (34%) the building of new plants.
(http://en.wikipedia.org/wiki/Nuclear_power_in_Finland)

For a more recent Spanish survey, refer to: *Años de mensaje antinuclear lastran aún más el futuro de esta energía*, Expansión, 21 April 2009.(http://www.expansion.com/2009/04/17/economia-politica/1239990809.html)

19 *Too cheap to meter* was the expression used in 1954 by Lewis Strauss, the first chairman of the Atomic Energy Commission, which became sadly notorious when it was cogently disproved by ensuing events.

built in a growing number of non-nuclear, developing countries. Given that the effort to overcome these challenges entails significant technical, political and economic efforts, they consider that it, "is justified only if nuclear power can potentially contribute significantly to reducing global warming, which entails major expansion of nuclear power. In effect, preserving the nuclear option for the future means planning for growth, as well as for a future in which nuclear energy is a competitive, safer, and more secure source of power". For all of the above, "from a public policy perspective, the scenarios that merit analysis are either a large-scale deployment or a phase-out of nuclear power over the next half-century". In their opinion, "it is misleading to focus on small increases in nuclear capacity justified by significant CO_2 reduction".

The authors accordingly considered a global growth scenario with a three-fold increase in the world nuclear fleet capacity by 2050 (1,000 to 1,500 GWe.[21] According to this study, such a deployment would avoid 800 million to 1.8 billion tonnes of carbon emissions annually, about 15%-25% of the increment in carbon emissions otherwise expected in a business-as-usual scenario, depending on whether a gas or coal plant is replaced, or about 8%-12% of total emissions by 2050. The study did not analyze other options for reducing carbon emissions, and the authors therefore point out that they can "reach no conclusions about priorities among these efforts for reducing emissions". However, they consider that it would be a mistake to exclude a priori any of the options without a proper cost-benefit analysis.

With regard to costs, the study concludes that in deregulated markets, nuclear power is not now cost competitive with coal and gas. However, if the investment could be reduced to less than 1,500 \$/k[22] the construction time could be shortened to 4 years and variable O&M costs could be reduced by 25%; the capital costs could be brought to a par with the other options; and, CO_2 emissions were penalised, then nuclear energy could achieve cost advantages.

With regard to operational security, the study considers that the serious accident rate - with release of radioactivity - should be less than one accident per 50 years. Given the planned increase in nuclear fleet, this implies a ten-fold reduction in the expected frequency of accidents in existing reactors. The authors consider that this is achievable based on new designs introduced by industry. They also consider finding a solution to proliferation as another fundamental prerequisite as "The current international safeguards regime is inadequate to meet the safety challenges of the expanded nuclear deployment contemplated in the global growth scenario." To this effect, they underline that "such conflicts between an underlying principle of the Nuclear Nonproliferation Treaty (NPT) and the aims of specific countries [such as Russia or the US, on the one hand, and Iran, on the other] could become more common in the nuclear growth scenario." The objective should be "to minimize the proliferation risks of nuclear fuel cycle operation". For this and other economic reasons, they propose the use of open, once-through fuel cycles, assuming that that there are adequate uranium resources available for the lifetime of the nuclear fleet (an assumption called into question by other studies).[23]

20 *The Future of Nuclear Power*: An interdisciplinary MIT study, MIT, 2003. (http://web.mit.edu/nuclearpower/)

21 Both Gordon Brown and John McCain have recently referred to a similar scenario, as well as the International Energy Agency in their *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*.
(http://www.independent.co.uk/news/uk/home-news/brown-says-world-needs-1000-extra-nuclear-power-stations-846238.html)
(http://www.johnmccain.com/informing/news/Speeches/13bc1d97-4ca5-49dd-9805-1297872571ed.htm)
(http://www.iea.org/Textbase/techno/etp/index.asp)

22 In 2003 dollars, and for the so-called *overnight* cost. That is to say, the cost incurred without the additional financial costs during construction or other related costs.

23 This is perhaps the Achilles heel of the scenario contemplated by MIT. The reasonably confirmed and estimated uranium reserves available at a cost compatible with the other assumptions are significantly below the needs of 1,500 reactors operating during 50 years. In fact, the Generation IV Forum itself considers that the available reserves are not sufficient even for the vegetative growth stage of the existing fleet. We contacted the authors of the report requesting further information on this point, and they responded that "unfortunately, we cannot expand upon the contents of the study, but we are convinced that there are adequate uranium reserves". The latest *Uranium 2007: Resources, Production and Demand* report by the NEA/IAEA estimates the identified amount of conventional uranium resources which can be mined for less than \$59/lb to be about 5.5 million tonnes. Undiscovered resources, without estimated costs, amount to 10.5 million tonnes. The program proposed by MIT shall require about 10 million tonnes of uranium up to 2050, and the financial costs were calculated with uranium at \$30/lb.

Lastly, the issue of waste, considered by the authors as "one of the most intractable problems facing the nuclear power industry", given that, "more than forty years after the first commercial nuclear power plant entered service, no country has yet succeeded in disposing of high-level nuclear waste". In their view, deep borehole disposal of waste is technically possible to ensure that radiation close to a waste disposal site shall not exceed 15 millirems per year for the first 10,000 years after final disposition. Nonetheless, they underline that the execution of a project is yet to be demonstrated or certain.[24] As regards the option of waste partitioning and transmutation, the authors believe that "a convincing case has not been made that the long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs". They propose pursuing deep borehole technologies that may offer opportunities to improve geological repositories at a lower cost and shorter timeframes than partitioning and transmutation.

Whether the MIT experts are right or not, or the solutions proffered are plausible or not, it is highly unlikely that such a large-scale nuclear deployment will be effective without US engagement, the participation of European countries, and the introduction of nuclear programs in most emerging and developing countries. Developments in the US and countries such as the United Kingdom and Germany are therefore essential. These countries alone, who together with Russia, France, Japan, South Korea, and China currently account for more than 80% of the world nuclear fleet, have the size and resources required to justify the investment needed to advance nuclear technology. However, the sheer scale of the nuclear expansion would have a significant impact on the structure of the nuclear industry and electric utilities in these countries.

Given that nuclear power has significant impact on public policies on safety, waste management, sites, proliferation, etc., governments should take special responsibility for ensuring that the industrial infrastructure developed, if any, is appropriate for solving this situation. Public affairs do not easily converge with the functioning of deregulated markets, and cannot be solved with perfunctory regulations as in other industries.[25]

All nuclear plants in operation today were built by State monopoly providers or vertically integrated electric utilities operating in a regulated market guaranteeing them a return on their investment, although some US and UK companies were later sold to third parties at enormous losses, and are now operating in a partially deregulated market. In Spain, the transition from a regulated market with cost-effective rates based on the cost-plus principle to a deregulated power generation market resulted in so-called Stranded Costs. More than half of said costs were allocated to nuclear plants, which could explain why they have already been virtually amortised and are, therefore, very profitable for their owners.[26]

In a traditional regulatory framework, the risks associated to construction costs, operation performance of the plant, fluctuations in fuel prices and other factors are assumed by the consumers and not the electric utilities, as any deviation is offset by rates. However, in the current European deregulation scenario, Directive 54/2003 considers it essential to promote and maintain competition in the power generation market and, as Claudio

24 The nuclear fleet proposed would call for the building of a repository similar to the one planned at Yucca Mountain (70,000 tonnes of spent fuel) every three or four years somewhere in the world. The Yucca Mountain site has been under study for over 20 years at a cost of 10 billion dollars. According to the original project, it was expected to become operational in 1998, but the planned last date is 2017. However, it is highly unlikely that it will ever come into operation, as the US Congress has reduced the 2008 budget by 21%, and the Obama administration has decided to terminate the program. In any case, if it were built with the planned capacity, it would not be able to hold the waste generated today in the US, awaiting disposal next to the reactors which generated them.

25 In fact, only scarcely deregulated countries, such as China, France, Russia or Korea, have concrete nuclear construction programs. Areva and EDF, both publicly owned French enterprises, are almost the only Western undertakings that are truly committed to investing in nuclear constructions, either in its own country or in other markets.

26 *El Libro Blanco sobre la Reforma del Marco Regulatorio de la Generación Eléctrica en España*, José Ignacio Pérez Arriaga, Ministry of Industry, Tourism, and Trade, June 2005, Chapter 6, pages 448 and following. (http://www.mityc.es/energia/es-ES/Servicios1/Destacados/LibroBlanco.pdf)

Aranzadi rightly observes in a recent article,[27] power utilities are responsible for "investing or not in new nuclear plants on the basis of the expected return on investment and the limitations set out in the specific legislation on the subject". He logically adds, "Both market and investment risks (timescale and costs) should be paid for by the companies," in line with the observations made in the MIT report.

So, do the current scenario and economic outlook suggest that the necessary conditions for a nuclear renaissance such as that announced in recent years - and explored in the MIT report - exist, or might the events of the 1970s be repeated, perhaps more quickly?

2.2.4 The US scenario: stalled plans

As already stated above, nuclear renaissance will only be possible if nuclearised Western countries, with some 25% of the world nuclear fleet, take the lead and amongst them, in particular, the United States. George W. Bush's administration launched the Nuclear Power 2010[28] as part of the National Energy Policy, with a view to restarting nuclear construction in the United States. The program was embodied in three consortia of businesses that were awarded funds to identify new sites, evaluate new reactor designs, evaluate the business case for building new nuclear power plants, and, above all, demonstrate untested regulatory processes to seek Nuclear Regulatory Commission (NRC) approval. The explicit objective was to build and operate one new nuclear power plant before the end of the decade, which called for the placing of a new reactor order in 2003. However, the plans did not materialise as expected, and the Bush Administration was required to increase the grants to the nuclear industry in order to encourage any enterprise to take the initiative. To this effect, the Bush Administration enacted the Energy Policy Act of 2005 (EPA 2005), which included many of the recommendations of the MIT experts.[29]

LThe EPA 2005 included various measures, such as tax incentives, grants and loan guarantees, aimed at incentivising the construction of six next generation reactors. In particular, the EPA 2005 includes nuclear-specific provisions that extend the Price-Anderson Act, which governs liability-related issues for nuclear facilities, for a 20 year period; authorise cost-overrun support of up to $2 billion for delays caused by disputes with the NRC; authorise a production tax credit of 1.8 US¢/kWh for the first 6,000 MWe from next generation nuclear power plants for the first eight years of their operation, subject to a $125 million annual limit; provide loan guarantees for up to 80 percent of the investment, to the total amount to be approved by the US Congress ($18.5 billion have been approved thus far); authorise $1.25 billion for building a demonstration nuclear reactor to generate both electricity and hydrogen; and, update tax treatment of decommissioning funds, generating about $1.3 billion in savings at nuclear power plants; in addition to other lesser measures which are expected to considerably facilitate future nuclear deployment.[30] All these measures aim to "jump-start"[31] the construction process, or as John Kane from the Nuclear Energy Institute (NEI) puts it, "simply an effort to get over that first hurdle".[32]

27 *Ni freno ni acelerador a la energía nuclear*, Claudio Aranzadi, El País, 12 de junio de 2008. (http://www.elpais.com/articulo/opinion/freno/acelerador/energia/nuclear/elpepiopi/20080612elpepiopi_12/Tes)

28 *A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010*, DOE, octubre 2001. (http://nuclear.gov/np2010/neNP2010a.html)

29 *Energy Policy Act 2005*, Congreso de los EE.UU. (http://www.epa.gov/oust/fedlaws/publ_109-058.pdf)

30 *2005 Energy Act: The Impacts on Nuclear Power*, ICF International, 2005. (http://www.icfi.com/Markets/Energy/Energy-Act/nuclear-power.pdf)

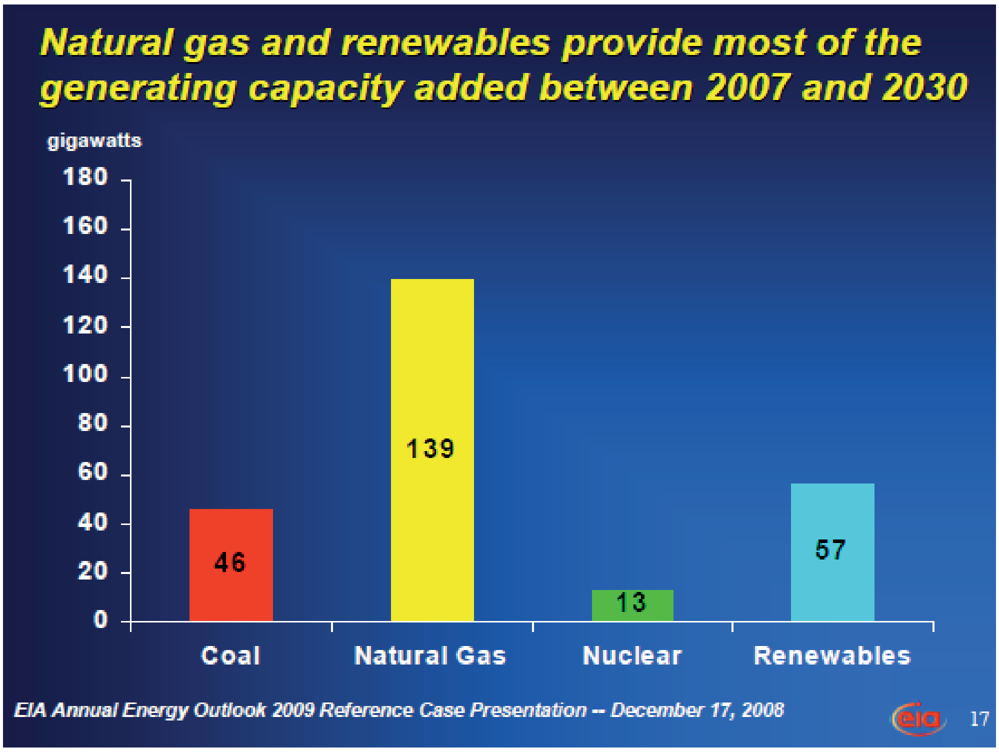
31 El término inglés empleado es "jump-start"; es decir, como arrancar un coche con un puente eléctrico.

32 *Energy Bill Raises Fears About Pollution, Fraud: Critics point to perks for industry*, Washington Post, 30 de julio de 2005. (http://www.washingtonpost.com/wp-dyn/content/article/2005/07/29/AR2005072901128.html)

Despite the above, and four years after coming into force of the EPA 2005, not a single US undertaking has decided to build a new nuclear plant, and some have even cancelled their existing programs. This incentive package appears to be insufficient to entice undertakings to building a few plants. For the time being, some seventeen undertakings or consortiums have expressed their interest in building up to thirty reactors. However, none have yet applied for a building permit or taken the final decision to build.[33] This is perhaps why the Energy Information Administration (EIA) of the US Department of Energy (DOE) does not expect more than 17 new reactors to come into operation by 2030. As shown in Figure 2.1.5, this is less than one reactor per year, with a net increase of only 13 GWe in nuclear generating capacity.[34]

According to the EIA, only 5% of the new capacity 255 GWe to be installed in the US over the next twenty years would be nuclear, which means that the nuclear component of the US mix – currently at about 20% – would continue to decline year on year. Conversely, natural gas (54.5%) and renewable energies (22%) provide most of the added generating capacity, with coal's share also still growing. In view of the statements by current DOE decision-makers and the approved fiscal stimulus plans, the figures may vary towards greater support for renewable energies, but not nuclear power, which has been excluded from these plans.[35]

Figure 2.1.5. Forecast of added generating capacity between 2007 and 2030 in the US



Source: EIA Annual Energy Outlook 2009 (early release) 34

33 This was the situation at January 2009. To monitor the events, refer to: (http://www.nei.org/keyissues/newnuclearplants/)

34 *Annual Energy Outlook 2009 (early release)*, Energy Information Administration, December 2008. (http://www.eia.doe.gov/oiaf/aeo/pdf/aeo2009_presentation.pdf)

35 *Gauging the Prospects for Nuclear Power in the Obama Era*, Kent Garber, US News & World Report, 27 March 2009. (http://www.usnews.com/articles/news/energy/2009/03/27/gauging-the-prospects-for-nuclear-power-in-the-obama-era.html)

Nevertheless, successive DOE forecasts in recent years show that significant nuclear renaissance in the US before the economic crisis was clearly rather uncertain, but the crisis is an added burden that suggest a more modest nuclear expansion than expected.[36] Other countries seem to be in the same situation, for instance South Africa, or, to a lesser degree, Turkey, who had outlined ambitious plans that have been recently cancelled. China alone seems to escape intact with their plans to increase their current nuclear electricity output from 2% to 4%-5% by 2030. [37-40]

Why is there not a single nuclear power plant in the pipeline in the US four years after the Bush Administration's unwavering commitment, a series of propitious measures, and Congress' approval of $18.5 billion in loans? As the senior officers of the US electric utilities repeat incessantly, the reasons are, yet again, economic. John Rowe (chairman of Exelon, the largest nuclear operator in the US), said, for instance, “I doubt if there's anybody more familiar with the financial risks of nuclear than I am, or anyone more concerned about it”. Going on to conclude that “we're not going to build the new nuclear plant without the federal loan guarantees”[41] A view shared also by Michael Wallace, vice-chairman of Constellation Energy and UniStart Nuclear consortium.[42]

Last year, the industry was stating that it would need $25 billion in 2008 and $50 billion over the next two years.[43] The most recent information suggests that they will need $122 billion in loans to cover the first 14 pending applications.[44] However, Commissioner Gregory Jacko of the NRC believes that not even these amounts are sufficient. According to his estimates, $500 billion in loan guarantees will have to be made available to build 50 new next generation reactors.[45] In June 2008, the Government Accountability Office (GAO),[46] the agency responsible for economic oversight of the US Congress, reported to Congress that there is almost 50% chance that the loan guarantees would have to be issued,[47] which indicate the level of uncertainty and economic scepticism towards nuclear renaissance in the United States.

How could it be that, in less than four years, the amount needed in federal loan guarantees has gone from several billion dollars to 500 billion dollars? We are again experiencing 1970s déjà vu : nobody really knows how much the new plants will cost, and each new estimate is much higher than the previous one, in a seemingly

36 *Economic Woes Delay US Nuclear Expansion*, Bernie Woodall and Scott DiSavino, Reuters, 17 March 2009. (http://www.reuters.com/article/idUSTRE52G4UF20090317)

37 *Eskom puts Nuclear Plant on Hold*, Roob M. Stewart, The Wall Street Journal, 7 December 2008. (http://online.wsj.com/article/SB122868998183686411.html?mod=googlenews_wsj)

38 *Nuked: Economic Downturn Threatens Nuclear Power Renaissance Too*, Keith Johnson, The Wall Street Journal, 8 December 2008. (http://blogs.wsj.com/environmentalcapital/2008/12/08/nuked-economic-downturn-threatens-nuclear-powers-renaissance-too/)

39 *Entergy Suspends Two Nuclear Plant Applications*, Reuters, Houston, 9 January 2009. (http://www.reuters.com/article/rbssUtilitiesElectric/idUSN0950363520090109)

40 *Turkey's First Nuclear Tender to be Cancelled Due to High Price Report*, Hurriyet Daily News, 23 January 2009. (http://www.hurriyet.com.tr/english/finance/10824979.asp?scr=1)

41 *America's Energy Future: Carbon, Competition and Kilowats*, John Rowe, The Brookings Institution, 12 February 2008. (http://www.brookings.edu/~/media/Files/events/2008/0212_energy/20080212_energy.pdf)

42 *Energy Bill Aids Expansion of Atomic Power*, E. L. Andrews y Matthew Wald, NYT, 31 July 2007. (http://www.nytimes.com/2007/07/31/washington/31nuclear.html)

43 Refer to reference 44.

44 *Nuclear Energy 2009: In Turbulent Times Still a Solid Value, Wall Street Briefing*, Marvin Fertel, Nuclear Energy Institute, February 2009.
(http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/presentations/in-turbulent-times-still-a-solid-value/)

45 *Government Loan Guarantees for New Nuclear Too Small*, Selina Williams, Dow Jones Newswire, 10 March 2008. (http://www.tmia.com/News/LoansTooSmall.htm)

46 Government Accountability Office
(http://www.gao.gov/about/index.html)

47 Nuclear Loan Guarantees: Another Taxpayer Bail-Out Ahead?, David Schissel, Michael Mullett and Robert Alvarez, Union of Concerned Scientists, March 2009.
(http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-loan-guarantees.pdf)

endless spiral. The MIT report estimated that total investment in a new nuclear plant would amount to about $2,000/kWe - based on data prior to 2003 -, and advocated 25% savings to make nuclear power competitive with coal and gas; however, the most recent estimates amount to more than three times MIT's figures.[48]

The most comprehensive and thorough public analysis available was carried out by the Florida Power&Light (FPL) for constructing two 1,100 MW Westinghouse AP-1000 reactors. The most recent estimate, from January 2008, on the project's total cost amounted to $12-18 billion.[49] That is to say, between 5,500 and 8,200 $/kW, more than double the estimates made by Progress Energy Florida (PEF) two years before, and four times MIT's 2003 estimate, but in line with Moody's estimate in October 2007,[50] which put the investment in about $6,000/kW. Three months later, PEF estimated also a project similar to the FPL project in $17 billion, three times the original estimate, and, in an unprecedented move, proposed a 3-4% annual increase in electricity rates to secure financial support for the planned construction period of ten years. "You can't avoid the notion that nuclear has an upfront cost for the customer", said Jeff Lyash, president of Progress Energy Florida,[53] in flagrant contradiction with those who claim nuclear power costs are lower that other alternative energies. Now, however, the economic crisis has dampened demand, and in response to protests by their customers, the electric utility has backpedalled on their plans to increase upfront the rates.[54]

Many projects under negotiation are also experiencing the same situation, to the point where companies such as MidAmerican Nuclear Energy Co., owned by the magnate Warren Buffett, and South Carolina Electric&Gas Co. have announced the suspension of their construction plans.[55] Others, like Duke Energy in South Carolina, prefer to keep their costs confidential so as not to give ammunition to their opponents.[56] If the EIA was already stating in 2005, when the estimated constructions costs were much lower, that "new plants are not expected to be economical".[57] It would appear that the situation has now noticeably deteriorated. As confirmed in The Wall

48 For a detailed analysis of the most recent investment estimates, refer to: Assessing Nuclear Plant Capital Costs for the Two Proposed Reactors at the South Texas Project Site, Arjun Makhijani, March 2008. (http://www.ieer.org/reports/nuclearcosts.pdf)

49 *Nuclear Costs Explode*, Russell Ray, The Tampa Tribune, 15 January 2008. (http://www2.tbo.com/content/2008/jan/15/bz-nuclear-costs-explode/)

50 New Nuclear Generation in the United States: Keeping Options Open vs. Adressing an Inevitable Necessity, Moody's Corporate Finance, October 2007. This report states: "we believe the ultimate costs associated with building new nuclear generation do not exist today and that the current cost estimates represent best estimates, which are subject to change". Moody's analysts foresee only one or two nuclear plants by 2015. (http://www.alacrastore.com/storecontent/moodys/PBC_104977)

51 To be precise, these estimates are not comparable to MIT's figures, given that the latter does not include all construction costs, whereas the figures provided by Moody's and the power utilities do include all such costs to get a more realistic estimate. As stated by Moody (refer to reference 48), "overnight costs often exclude owner's cost and price escalation. Instead, we are concerned with the total all-in costs. An analogy would be the purchase price of a house which excludes the costs of appliances, furnishings, and landscaping, etc."

52 What *Progress Energy Florida* is proposing that consumers assume not only the risk of higher future rates stemming from overcosts and delays in the construction of nuclear reactors, but also, pay more for the electricity generated by other plants while construction is in progress, during a ten year period, in order to offset financial costs. It is highly unlikely that legislators will allow this practice nor the customers will accept it.

53 *Nuke Plant Price Triples: Progress energy's planned plant costs $17 billion*, Asjyln Loder, St. Petesburg Times, 11 March 2008. (http://www.sptimes.com/2008/03/11/State/Nuke_plant_price_trip.shtml)

54 *Progress Florida pares early nuclear charges*, Reuters, Houston, 17 March 2009. (http://uk.reuters.com/article/idUKN1729706420090317)

55 Warren Buffett rejects Nuclear Plant in Idaho due to high cost, Andrea Shipley, SunValley, 29 de enero de 2008; SCE&G suspends plans to ask US NRC for license to build new nukes, Platts, 28 January 2008. (http://www.sunvalleyonline.com/news/article.asp?ID_Article=4581) (http://www.platts.com)

56 Cost of nuclear plant fuels battle: Price of new plants in North and South Carolina would be ammunition for opponents if utilities didn't hold info close, John Murawski, The News & Observer, 24 April 2008. (http://www.newsobserver.com/business/story/1048035.html)

57 *Annual Energy Outlook 2005*, Energy Information Administration, February 2005, page. 6. (http://tonto.eia.doe.gov/ftproot/forecasting/0383(2005).pdf)

Street Journal when it states that "the high cost could lead to sharply higher electricity bills for consumers and inevitably reignite debate about the nuclear industry's suitability to meet growing energy needs".[58]

2.1.5 US industry urges realism and caution

At the Nuclear Energy Institute 2008 General Assembly, John Rowe, president of Exelon Corp. (the largest nuclear electricity operator in the US), described the frame of mind of the nuclear industry in that country. "We cannot afford to let ourselves be carried away on the enthusiasm of press releases ... We must create realistic expectations ... The "renaissance" of nuclear power suggest that it will unfold slowly over time ... Perhaps four to eight new plants as early as 2016 or so. If those first plants are working to schedule within budget estimates, without licensing difficulties, and with continued public policy support, a second wave could be under construction as the first wave reaches commercial operation."

Nevertheless, "cost confidence in new nuclear construction is hard to come by ... No reactor vendor is offering solid price certainty, and even the rough preliminary estimates are increasing rapidly". And, as to the timeframe, "nothing will chill the rebirth of nuclear power more quickly than finding ourselves 18 months into construction on a project and 18 months behind schedule", in clear reference to what happened in Finland,[59] which will analyzed later on in detail. "These costs are daunting," continues John Rowe, "especially compared to the book equity or market capitalization of the companies building them ... Companies are not willing to bet the farm on the success or failure of a single project ... We need to find new and innovative ways to share the risks". Moreover, "Yucca Mountain is stalled and there has been no progress on an alternative ... And, the requisite stability in public policy to support a multi-billion dollar long-term investment continues to be a risk we cannot control, or predict".[60]

One would be hard pressed to summarise better the existing doubts on the US nuclear program. Doubts concerning not only the possibility of launching a large-scale construction program to mitigate the effect of climate change and the decline of fossil fuels, as stated in the MIT report, or even something less ambitious like replacing the 104 reactors currently in operation, but rather the mere possibility of building by 2030 the 25 to 30 reactors that John Rowe believes are necessary to avert irreversible decline.

Doubts shared and further developed by the Council on Foreign Relations (CFR) in a recent report on the risks and benefits of nuclear energy. It is important to bear in mind that even the lifetime of existing reactors were extended for 20 years, the US would have to close, decommission and replace all 104 reactors before the middle of the 21st century. This means building a new reactor every four or five months over the next 40 years. The CFR considers that "regardless of other considerations, this expansion presents a daunting challenge, and, for this reason alone, nuclear energy is not a major part of the solution to US energy insecurity for at least the next fifty years".[61]

The renewal of the existing world nuclear fleet is also called into question. Even if all constructions projects identified by the WNA were completed successfully over the next 15 years; the most nuclear energy intensive

58 *New Wave of Nuclear Plants Faces High Costs*, Rebecca Smith, The Wall Street Journal, 12 May 2008. (http://online.wsj.com/article/SB121055252677483933.html)

59 Refer, for instance, to *Power Failure: What Britain should learn from Finland's nuclear saga*, Michael Savage, The Independent, 16 January 2008. (http://www.independent.co.uk/news/science/power-failure-what-britain-should-learn-from-finlands-nuclear-saga-770474.html)

60 *Nuclear Energy 2008: State of the Industry*, John Rowe, Nuclear Energy Assembly, NEI, Washington, 6 May 2008. (http://www.nei.org/newsandevents/speechesandtestimony/2008_speeches_and_testimony/rowespeech_050608/)

61 *Nuclear Energy: Balancing Benefits and Risks*, Charles D. Ferguson, Council on Foreign Relations, April 2007. (http://www.cfr.org/publication/13104/nuclear_energy.html)

forecasts by the International Atomic Energy Agency came true (90 new reactors before 2020),[62] and the construction period were extended up to 2050, the new constructions available by 2050 would generate 360 GWe, slightly less that the amount required to replace existing output.[63]

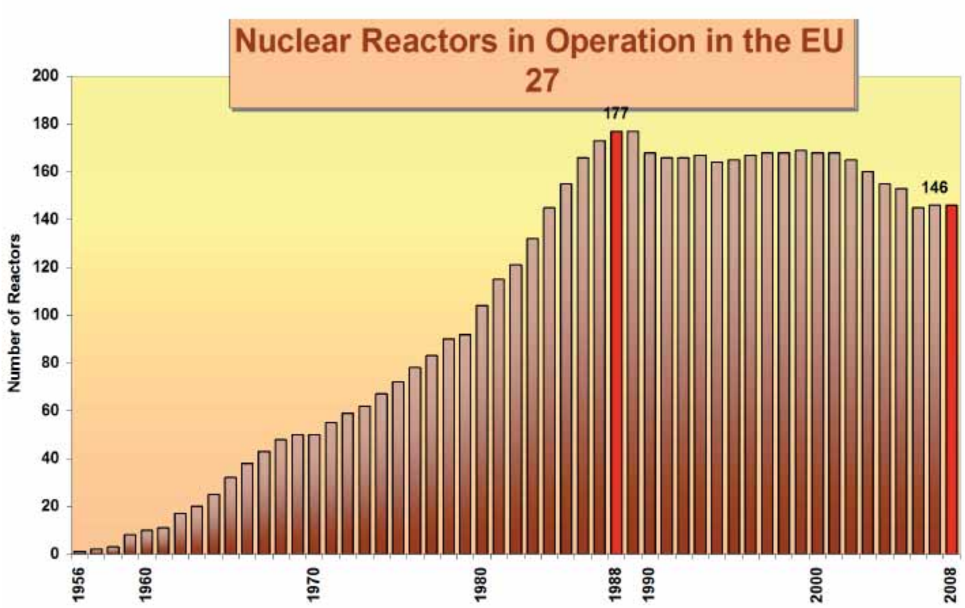
If that is the case, i.e., if the replacement of the existing fleet when it is no longer operational is not realistic even in the most ambitious scenario conceivable, what sense and purpose is served by the nuclear option as a decisive element in preventing climate change and the decline of fossil fuels?

2.1.6 European scenario: Finland, United Kingdom, France, Sweden, and Italy

The share of nuclear energy in the electricity mix has decreased more sharply in the European Union than in the rest of the world, owing possibly to the closure of old Soviet-era reactors in Eastern Europe.

As Figure 2.1.6 shows, the number of reactors has dropped from 177 in 1988 to 146 by the end of 2008 (nearly one third of the world total). Most of these reactors (about 125) are located in eight countries: France, Germany, Great Britain, Sweden, Spain, Switzerland, Belgium, and the Netherlands. In 2007, nuclear power produced 28 percent of Europe's electricity, although almost half of the electricity was generated in France.

Figure 2.1.6 Trends in nuclear generating capacity in EU-27



Source: The World Nuclear Industry Status Report 2008 [64]

62 For the nuclear industry perspective, go to: http://www.world-nuclear.org/info/inf17.html. By comparison, Moody's stated that "many of the current expectations regarding new nuclear generation are overly ambitious ... Moody's does not believe the [US nuclear] sector will bring more than one or two new nuclear plants on line by 2015. In fact, the timing associated with commencing construction and making the next nuclear unit commercially available could be well beyond 2015 and the costs associated with the next generation of nuclear build could be significantly higher ... than the estimates cited by many industry participants", Washington Post, July 2008.
http://newsweek.washingtonpost.com/postglobal/energywire/2008/07/fun_facts_about_nuclear_financ.html

63 Refer to detailed calculations in reference 99.

64 *2008 World Nuclear Industry Status: Western Europe*, Mycle Scheider, September 2008 (http://www.thebulletin.org/web-edition/reports/2008-world-nuclear-industry-status-report/2008-world-nuclear-industry-status-re-1)

There are currently four reactors under construction in EU-27, two of which are located in Western Europe: one in Finland and another twin reactor in France. These are the first two reactors built according to a new French, third-generation design called EPR (European Pressurized Reactor), with 1,600 MWe rated output. France is promoting this design at the international level and for eventually replacing its own reactors. Other than in France and Finland, no new reactor order has been placed in Western Europe since 1980. Unless a broad-based policy of licensing extensions is introduced, one third of European reactors shall be closed before 2025. Thus, Europe faces a challenge similar to that of the US: how to replace an ageing nuclear fleet and what are the possibilities of extending the lifetime of this fleet before mid-century?

We will now focus on Finland, France and the United Kingdom, since these countries have the most advanced plans for new builds. Sweden and Italy have recently announced their intention to change their policy on nuclear energy, but neither country has developed concrete plans for commencing new constructions.

Finland

Finland has four reactors, which generate 29% of its electricity. In December 2003, and after a long, drawn-out political and social debate, it became the first Western country to place a reactor order after 15 years of nuclear drought. The decision was mainly based on a comparative analysis[65] of various power generation options where it was concluded that the nuclear option was the most efficient in economic terms. However, the desire to reduce dependence on Russian gas also had a significant bearing on the decision.

The power utility TVO signed a turnkey contract with Areva-Siemens consortium to build a 1,600 MWE EPR at Olkiluoto under very favourable terms: fixed price (about ?3 billion), 4-year construction period, cheap financing,[66] for France to build a replica of new Flamanville reactor, etc. The terms and conditions obtained by Areva, who was very keen on securing the first order in order to breathe life into the market (as Westinghouse and General Electric had done in the 1960s when they sold their first reactors at a loss), cannot be transposed to future projects. Moreover, the electricity generated by this reactor is not intended for a deregulated market, but rather for self-consumption, at prime cost, by the consortium that placed the order, comprised of electricity intensive industries and city councils.

According to estimates calculated under certain assumptions, this cost that would be highly competitive, about ?22/MWh. The current generating costs for a French EPR, as will be outlined below, are about ?60/MWh, nearly three times the cost TVO had calculated.

The real situation of the project was very different from the expected. It appears that what was intended as an icon of nuclear renaissance has turned into yet another demonstration of how the nuclear industry can repeat the mistakes which led it to the current difficult situation. “Olkiluoto 3 would demonstrate that nuclear energy was the obvious solution to growing concerns about CO_2 emissions, high fossil fuel prices and dependence on imported energy sources”, said the Financial Times at the end of 2008. Instead, it continues, “Instead, Olkiluoto has become a showcase for the hassles, delays and cost-overruns that critics say always bedevil nuclear projects”.[67]

65 *Nuclear Power: Least-Cost Option for Base-Load Electricity in Finland*, Risto Tarjanne & Sauli Rissanen, The Uranium Institute 25th Annual Symposium, 2000.
(http://www.world-nuclear.org/sym/2000/pdfs/tarjanne.pdf)

66 Siemens, who built the non-nuclear part of the facility, received a ?2.7 billion loan from Bavarian Landesbank at 2.6% interest rate, which covered more than 60% of the contract value. The Compagnie Francaise d’Assurance pour le Commerce Exterieur, the French public agency for promoting foreign trade, contributed about ?1 billion to the project, also at a low interest rate

67 *Finland’s symbol of resurrection becomes showcase for hassles, delays and cost-overruns*, Robert Anderson, Financial Times, November 2008.
(http://www.ft.com/cms/s/0/8fca40e6-a946-11dd-a19a-000077b07658.html)

In 2009 so far, the situation has merely deteriorated beyond the worst predictions for this project, which, 46 months after its commencement, is 38 months behind schedule. In its last report,[68] Areva had provisioned ?1.7 billion for losses relating to the project – although completion is still more than three years away – and faces a ?2.4 billion damage suit filed by TVO for delays in the project.[69] Areva, for its part, has struck back suing TVO for ?2 billion for possible breach of contract terms. Siemens, the other member of the construction consortium, has decided to pull out of the venture, and has demanded that Areva buy its 34% stake for ?2 billion.[71] All of the above places Areva in a very difficult financial situation[72] in which the French government, as the majority stakeholder, will probably have no alternative other than to authorise a capital increase by the transfer of assets or merger of this company with another capable of absorbing its multimillion losses.[73]

In short, the Finnish experience does not appear to encourage other countries into venturing down this path, at least for the time being.

France

If the oil crisis was the cause of the nuclear decline in the US, France is the poster child for the opposite. After World War II, France did not relinquish its right to have a "force de frappe" or place itself under the US nuclear umbrella. It built the first generation of weapons-grade plutonium reactors, of which Vandellos I was one of the last to be transformed into power generators. For reasons unrelated to this case, the nuclear issue became part of the French national identity, with broad social support under the banner of "le rayonnement de la France".[74] In the midst of the 1973 oil crisis, the State machinery was set in motion, under the slogan "without oil, without gas, without coal, without option", by the nationalised electricity and nuclear sectors, which now include EDF and Areva, and which Sarkozy proposes to use as key elements of France's presence on the international stage.

France is today the most nuclearised country in the world with 77% of nuclear electricity, which, however, only accounts for 16% of final energy consumption. This strategy does not seem to have yielded significant benefits on electricity costs, competitiveness of its industries, nor level of energy independence.[75] Whether Sarkozy's frenetic activity, signing memorandums of understanding with several countries, will actually result in contracts or not remains to be seen. Other than the Finnish fiasco, France is only selling reactors to itself, be it to EDF, its subsidiaries, Gas de France-Suez, or, perhaps Total. Something that, on the other hand, is essential to keep Areva in the contest, pending the arrival of orders that will bring the long-awaited global nuclear renaissance. In the meantime, EDF's international nuclear strategy, in both Great Britain and the US, is being affected by the international economic crisis.[76]

68 Areva 2008 Annual Results, press release. (http://www.areva.com/servlet/BlobProvider?blobcol=urluploadedfile&blobheader=application%2Fpdf&blobkey=id&blobtable=Downloads&blobwhere=1235488433969&filename=CP_RN_2008_Version+anglaise.pdf)

69 *Finlande: TVO réclame 2,4 mds EUR à Areva et Siemens pour le retard de l'EPR*, France Press, 28 January 2009.

70 *Areva en Appelle à un Arbitrage sur son Chantier Nucléaire Finlandais*, Jean-Michel Bezat, Le Monde, 21 December 2008.

71 *Siemens to Pull Out of Areva Nuclear Venture*, Peggy Hollinger & Daniel Schäffer, Financial Times, 23 January 2009. (http://www.ft.com/cms/s/0/416aedbc-e93b-11dd-9535-0000779fd2ac.html)

72 *L'Etat met Anne Lauvergeon, presidente du directorate d'Areva, sous pression*, Les Echos, 30 de enero de 2009. The 2009 budget was rejected by the government representatives, who set up a special supervision committee until the means for increasing the State's capital is found.

Areva chairman quits and adds to troubles at nuclear group, Terry Macalister, The Guardian, 4 April 2009. (http://www.guardian.co.uk/business/2009/apr/04/areva-nuclear-group-chairman)

73 *Du Changement au Capital d'Areva*, Le Journal de Dimanche, 12 March 2009. (http://www.lejdd.fr/cmc/scanner/economie/200911/du-changement-au-capital-d-areva_194019.html)

74 Refer, for instance, to *Le Rayonnement de la France: Énergie nucléaire et identité nationale après la seconde guerre mondiale*, Gabrielle Hecht, Editions la Découverte, 2004.

75 *Nuclear Power in France: Beyond the Myth*, Mycle Schneider, December 2008. (http://www.greens-efa.org/cms/topics/dokbin/258/258614.beyond_the_myth@en.pdf)

76 *A EDF se le atragantan todos sus matrimonios nucleares*, Javier Aldecoa, March 2009. (http://www.capitalnews.es/articulo.php?n=090317015656)

France, with 59 reactors representing 55% of its power generation fleet, has an enormous surplus of generation capacity, probably owing to demand forecasting errors used to export surplus electricity to neighbouring countries at a low price. Peak consumption is 86 GWe in winter, whereas the installed capacity is 116 GWe. This surplus has encouraged an inefficient use of electricity for heating homes and water. Thus, despite committing 12 reactors to exporting electricity, it has to import electricity frequently to meet peak demands.

With this overcapacity, and a relatively young reactor fleet, France does not need to build any reactor in many years. Yet, owing to a variety of reasons, it is building an EPR at Flamanville, and has announced the construction of a second unit at Penly, and perhaps even a third. Firstly, because it aims to play a leading role in the world market of next generation reactors, and, therefore needs to practice what it preaches. Secondly, to ensure the operation of its nuclear industry, whose fleet will eventually have to renewed (it should be borne in mind that, for instance, 40% of EDF's O&M personnel will reach retirement age before 2015). Lastly, in order to offset lack of international orders, Areva has made, and will continue to make, huge investments to maintain its position in the world market.

The construction of the new EPR at Flamanville (a requirement stemming from its commitments in Finland), is also not with drawbacks. From the outset, it has suffered delays and more than 30% cost increases. Enterprises such as AcelorMittal, Air Liquide or Solvay, which had entered into an electricity supply contract with EDF for a 24 year period, in exchange for a stake in the plant, have seen how the cost per MWh, linked to the plant's cost, has increased from the initially anticipated 46 ?/MWh to the recently reviewed 54 ?/MWh, and, they have already been forewarned that the final cost will reach 60 ?/MWh. On hearing this information, the president of FORTIA, the Spanish association of electricity-intensive industries, has stated that “on learning of the situation of the future plants in France and Finland”, they no longer contemplate participating in similar projects.[77]

In summary, the French nuclear scenario is specially atypical, as it stems from a political and industrial agenda planned decades ago by the highest French governmental authorities - in which, incidentally, the Parliament never partook -, and subject to military and national identity considerations. Hence, it is does not appear replicable in other countries. France should not be seen as a country contemplating whether to embrace a nuclear future or not, but rather as a country that already made that decision long ago, and now seeks to maximise the industrial return, although the outlook is rather uncertain. If it were unable to secure this return, it would face the daunting prospect of replacing its huge reactor fleet, and incurring the monumental cost of decommissioning and waste treatment, for which EDF has not provisioned adequately.

77 *Las nucleares participadas por la industria disparan sus costes*, Javier L. Noriega, Cinco Días, December 2008. (http://www.cincodias.com/articulo/empresas/nucleares-participadas-industria-disparan-costes/20081212cdscdiemp_16/cdsemp/)

United Kingdom

Just like the French scenario should not be considered representative of the future of nuclear energy in other countries, what happens in the United Kingdom may serve as reference in countries less committed a priori to the nuclear option.[78] Unlike France, the history of the UK nuclear industry has until recently been a history of technical, economic, and political failure.[79] A failure which it now seeks to avoid with a second phase of constructions, which according to the British government, will have to be funded by the private sector, without grants or subsidies.

The British market would set the standards until the nuclear option can survive in a deregulated and competitive environment. The Prime Minister, Gordon Brown, said, "Nuclear power is a tried and tested technology. It has provided the UK with secure supplies of safe, low-carbon electricity for half a century. New nuclear power stations will be better designed and more efficient than those they will replace. More than ever before, nuclear power has a key role to play as part of the UK's energy mix".[80] With such high profile support from the highest government authorities, the ball is now in the power utilities' court that has to decide whether to invest.

The British nuclear program was also the offspring of military plutonium produced by first generation, Magnox dual-use reactors. At the end of the 1950s, the British authorities decided to develop a new generation of AGRs, totally different from the models chosen by other countries, which had proved to be complete technological failures. In the 1980s, Margaret Thatcher's government planned the construction of ten new reactors, this time with standard PWR technology, as means of pressure against mining unions; however, it only built one.

Owing to the lack of interest among private investors, nuclear reactors were segregated from the rest of the electricity sector, remaining in the public sector until the first phase of privatisations in 1989. They were finally privatised in 1996 as British Energy; however, the Magnox reactors and fuel reprocessing facilities that still showed exceptional losses were excluded. At the beginning of 2000, British Energy was unable to compete in the deregulated electricity market and had to be rescued by the British government. In 2004, British Energy's decommissioning and waste management liabilities were segregated, and the Nuclear Decommissioning Authority, responsible for decommissioning ageing reactors and fuel processing facilities over the next 125 years at an estimated cost of in excess of ?100 billion, was set up. These costs were neither provisioned for nor included in past rates, and, therefore, the will have to be paid by the taxpayer.[81]

British Energy was downscaled to eight nuclear plants, and its greatest asset is probably the sites were the new generation of reactors will be built next to the old ones. In September 2008, EDF bought British Energy and explored the possibility of building four EPRs and selling the other sites, with a view to allowing other undertakings to build additional reactors.

The situation of the British electricity sector is rather precarious, given than almost 30% of its generating capacity must be replaced over the next twenty years (mainly, nuclear and coal). As shown in Figure 4.8, even if the lifetime of the three best performing nuclear plants were extended, there will be a significant drop in nuclear capacity around 2015, which could endanger the country's electricity supply if it is not properly addressed.

78 *A Level Playing Field: Nuclear energy is about to face a major test in the UK*, Guy Chazan, Wall Street Journal, 30 June 2008. (http://online.wsj.com/article/SB121432271512200201.html?mod=dist_smartbrief)

79 Refer, for instance, to The British Nuclear Industry: Status and Prospects, Ian Davis, Nuclear Energy Futures Paper nº 4, Center for International Governance Innovation.
(http://www.igloo.org/community.igloo?ro=community&ro_script=/scripts/folder/view.script&ro_pathinfo=%2F{7caf3d23-023d-494b-865b-84d143de9968}%2FPublications%2Fresearch%2Fnucleare%2Ftest%2Fnef4&ro_output=xml)
Also, *Vodoo Economics and the Doomed Nuclear Renaisance*, Paul Brown, Friends of the Earth, May 2008. (http://www.foe.co.uk/resource/reports/voodoo_economics.pdf)

80 *Meeting the Energy Challenge: A White Paper on Nuclear Power*, Fireword by Gordon Brown, January 2008. (http://nuclearpower2007.direct.gov.uk/docs/WhitePaper.pdf)

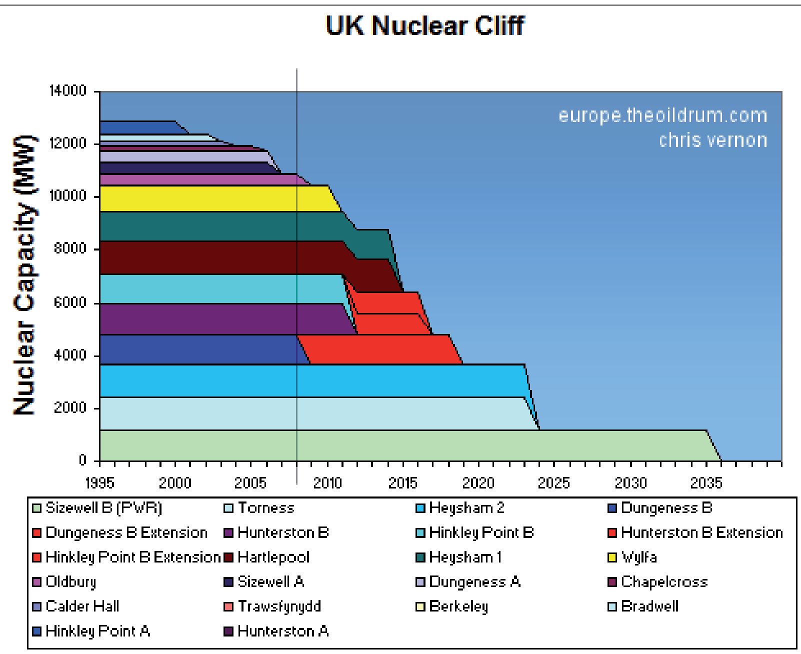
81 *Nukenomics: The commercialization of Britain's nuclear industry*, Ian Jackson, Nuclear Engineering International Special Publications, 2008.
(http://www.amazon.co.uk/Nukenomics-commercialisation-Britains-nuclear-industry/dp/1903077559)

Thus, given current construction schedules and bottlenecks, it is not possible for EDF to build four EPRs before 2015, especially since it does not yet have any detailed plans or orders. Assuming, with a good dose of optimism, that all four reactors are put into operation around 2020, we would have the situation described in Figure 4.9, with a significant capacity shortfall between 2015 and 2020, which will probably only be corrected by extending the lifetime of other plants, however, at a rather low level of availability. In order to rebalance the nuclear mix shown in this Figure, it would be necessary to build four additional reactors to those already planned by EDF, merely to recover 1990 levels of nuclear capacity by 2030.

The British government has identified potential sites for new plants, all located at or close to existing plants. However, at the same time, experts warned that, in the best-case scenario, the first plant would not be operational until 2017. It is now inevitable that the gap will be filled by the rapid construction of combined-cycle power stations. The British electricity sector will therefore have to double its investment due to the lengthy construction period for nuclear plants. All of which casts a shroud of doubt over the future of these plans. [82]

The British case promises to be a litmus test of the technical and financial capacity of European nuclear industry and power utilities to solve the world energy crisis and to recover previous levels of coverage. The events that have yet to unfold over the next years in this market can be a good predictor of the nuclear future, at least, in Europe. An issue yet to be solved is how far can and will a European government subject to EU regulations go to promote nuclear energy in its country, and how much will it cost.

Figure 2.1.7. Trends in Nuclear Generating Capacity in the United Kingdom without New Builds

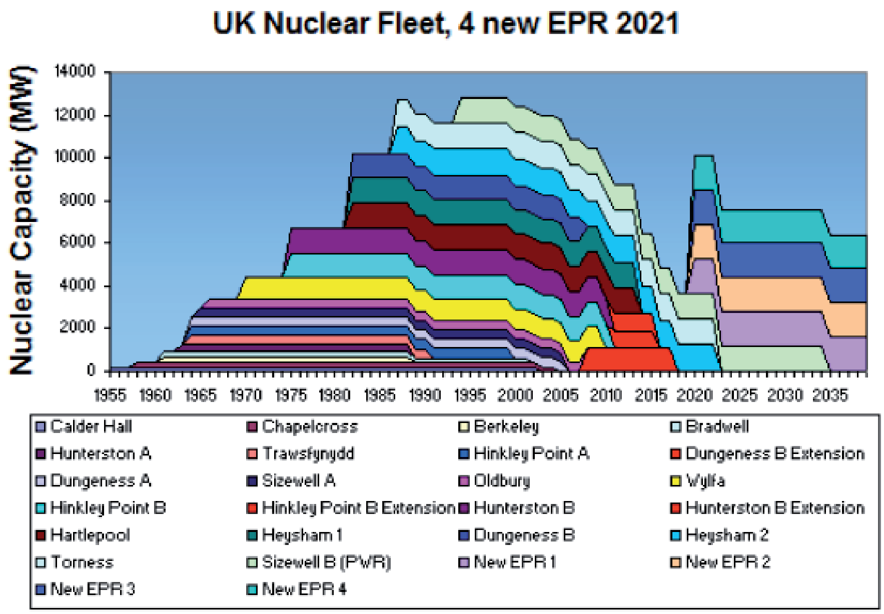


Source: Nuclear Britain, The Oil Drum Europe[83]

82 *All-clear for nuclear plants "too late to plug power gap"*, R. Pagnamenta, The Times, 16 April 2009. (http://business.timesonline.co.uk/tol/business/industry_sectors/utilities/article6101502.ece)

83 *Nuclear Britain*, Chris Vernon, The Oil Drum Europe, January 2008 (http://europe.theoildrum.com/node/3486)

Figure 2.1.8 Trends in Nuclear Generating Capacity in the United Kingdom with 4 new EPRs in 2021



Source: Nuclear Britain, The Oil Drum Europe [84]

2.1.7 Limitations of Nuclear Energy

Nuclear power generates approximately 15% all world electricity. And because it is a low-carbon source of around-the-clock power, it has received renewed interest as concern grows over the effect of greenhouse gas emissions on our climate. This raises the question as to whether nuclear energy should be promoted a strategy for reducing emissions from the energy sector

Quantitative limitations of nuclear renaissance

As already stated above, the promotion of nuclear energy as a strategy for mitigating climate change would only be meaningful against the background of significant growth of the nuclear fleet. However, as Joe Romm explains,[84] nuclear technology's own myriad, quantitative limitations will constrain its growth, especially in the near and medium term. These include:

- Prohibitively high, and escalating, capital costs.
- Very long and uncertain construction times that considerably increase financial and material costs.
- Production bottlenecks in key components needed to build plants, such as the reactor vessel, and absence of enterprises and knowledgeable workers.
- Unresolved problems with the availability and security of long-term high-level waste storage.

84 *The Self-Limiting Future of Nuclear Power*, Joe Romm, Center for American Progress Action Fund, June 2008. (http://www.americanprogressaction.org/issues/2008/pdf/nuclear_report.pdf)

- Concerns about uranium supplies and costs in a growing nuclear fleet.
- Large-scale water use amid shortages.
- Problems of incompatibility with renewable energy sources due to the inability to regulate both.
- High electricity prices from new plants.

Due to the above reasons, it is highly unlikely that nuclear energy will play a leading role in the global effort to limit temperature increases to less than 2ºC above current temperature. It is therefore undesirable to promote nuclear energy in the context of the fight against climate change, at least in the next 50 years. To stabilise atmospheric CO_2 concentration below 450 ppm, it is necessary to reduce global emissions from 2020 on, and maintain CO_2 emissions at less than 4 billion tonnes per year by 2050.

To reduce emission, Stephen Pacala and Robert Socolow from Princeton University have pointed out the need to find seven "wedges", each of which reduces emissions to the atmosphere that increases linearly until it accounts for 1 GtC/year of reduced carbon emissions in 50 years.[85] The Keystone Center, in a study funded by the nuclear industry,[86] has calculated what is needed to fill a stabilization wedge with nuclear energy:

- Build 14 new plants per year on average over the next 50 years, and about 7.5 plants more to replace the existing fleet. Almost two plants per month over 50 years.
- Increase five-fold uranium production, or develop and deploy a new generation of plutonium or thorium breeder reactors.
- Build 11-22 additional uranium-enrichment plants to supplement the existing 17 plants in the world, or the appropriate irradiated fuel reprocessing facilities.
- Build 18 additional nuclear fuel manufacturing facilities, whilst maintaining the existing 17 facilities.
- Build 10 geological repositories of the size of Yucca Mountain to store spent fuel, or reprocess all irradiated fuel and perform selective transmutation.

To begin with, it would be necessary to build 25 reactors over 40 years starting from next year, a pace never achieved before, even during the peak of the reactor construction period in the 1980s, and if it were at all possible, it would take decades to achieve.

A challenge that would currently appear to be impossible, taking into account the existing production bottlenecks in key components. Decades of nuclear moratorium have resulted in fewer certified industrial nuclear constructors and skilled workers. For instance, there are only two OECD-certified enterprises in the world for building the one-piece, metal reactor vessels. The optimism about nuclear renaissance prospects without taking into account the industrial part is somewhat surprising. The increase in industrial capacity required would entail a commitment to nuclear growth that few companies are willing to make. It is precisely these limitations in industrial capacity and skilled human resources, combined with price increases in raw materials which produce enormous cost overruns in the few projects still being carried forward.

85 *Stabilization Wedges: Solving the climate problem for the next 50 years with current technologies*, Stephen Pacala, Robert Socolow, Science, Vol. 305, no. 55686, pp. 968-972, 13 August 2004.
(http://www.sciencemag.org/cgi/content/abstract/305/5686/968)

86 *Nuclear Power Joint Fact-Finding*, The Keystone Center, June 2007.
(http://www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf)

Fuel and waste limitations

Current uranium production is yet under obstacle in the path to nuclear renaissance, since existing mines under production generate only 60% of the uranium consumed in the world's nuclear reactors, while the rest comes from military and government stockpiles. It would not be easy to increase uranium production five-fold, specially since it takes decades to prepare a new uranium mine for production, and, according to the vice-president of the mining business unit at Avera, it is not possible to reduce this period.[87] . On the other hand, new uranium mines will most likely be found at deeper depths than ever before and with lower concentrations, resulting in higher CO_2 emissions and correspondingly higher environmental impact in producer countries.[88] This scenario not only calls into question actual emission saving, but also increases costs.

The theoretical possibility of a new generation of plutonium or thorium reactors (breeder reactors), which would increase 100% the energy recovery efficiency of natural uranium, has always been contemplated in the debate on fuel shortage. However, the history of this type of reactors, for instance, the French Superphoenix or Japanese Monju, have been discouraging, owing both to the costs and safety and operation concerns, as already explained in Chapter 2.2.

On the other hand, the reuse of spent irradiated fuel calls for complex electrochemical processes for fuel reprocessing, with little prospect of economic success. According to the nuclear physicist Frank N. von Hippel, former science advisor to Clinton, and an eminent expert on this matter, the reprocessing of irradiated fuel at existing facilities has three drawbacks: "the extraction and processing cost is much more than the new fuel is worth"; "recycling the plutonium reduces the waste problem only minimally"; and, the separated plutonium can readily serve to make nuclear weapons, as a result "much effort has to be expended to keep it secure until it is once more a part of spent fuel". [89]

The reprocessing of spent fuel to fill one of Pacala & Socolow's wedges calls for the construction of 35 new reprocessing facilities, in addition to those in operation in France, Russia, and the United Kingdom. The last reprocessing facility, costing some $20 billion dollars, a threefold increase over initial estimates, was built in Japan over 15 years.[90] It took more than 25 years to bring the THORP reprocessing facility in the UK into operation,[91] and it is currently closed due to operating and safety problems,[92] after it became the center of a political scandal when Malcolm Wicks, the British Energy Minister, was compelled to admit that, the plant had only produced a total of 5.2 tonnes of MOX (mixed uranium and plutonium fuel) since it opened in 2001, despite promises it would produce 120 tonnes a year. When asked about the cost to the taxpayer, the Minister declared it was "commercially confidential".[93] The French facility at La Hague[94] has the world's largest production capacity; however, it only recycles 1% of recovered material as new fuel. EDF, for instance, has 12,000 tonnes of

87 In *Challenging or Easy? Natural uranium availability to fuel a nuclear renaissance*, Tim Gitzel, World Nuclear Association Annual Symposium 2005, the vice-president of Areva's mining business unit has estimated that the time needed to prepare a uranium mine for production is 20 years.
(http://world-nuclear.org/sym/2005/pdf/Gitzel.pdf)

88 Sustainability of Uranium Mining and Milling: Toward Quantifiying Resources and Eco-Efficiency, Gavin Mudd & Mark Diesendorf, Environmental Science & Technology, nº 42, 2008.
(http://pubs.acs.org/doi/abs/10.1021/es702249v)

89 *Nuclear Fuel Recycling: More Trouble than it's Worth*, Frank von Hippel, Scientific American, April 2008. (http://www.scientificamerican.com/article.cfm?id=rethinking-nuclear-fuel-recycling)

90 http://en.wikipedia.org/wiki/Rokkasho_Reprocessing_Plant

91 http://en.wikipedia.org/wiki/Thermal_Oxide_Reprocessing_Plant

92 *'Shambolic' Sellafield in crisis again after damning safety report*, Geoffrey Lean, The Independent, 3 February 2008. (http://www.independent.co.uk/environment/green-living/shambolic-sellafield-in-crisis-again-after-damning-safety-report-777551.html)

93 *What a waste: dream of free energy turns into £3bn-a-year public bill*, Terry Macalister, The Guardian, 29 May 2008. (http://www.guardian.co.uk/business/2008/may/29/britishenergygroupbusiness.nuclear1)

94 http://en.wikipedia.org/wiki/COGEMA_La_Hague_site

irradiated fuel stored there, the equivalent of over ten years' throughput at the current rate of reprocessing. According to the French government, the investment and operating costs would need to be half the costs for the current La Hague facilities in order for reprocessing to be economically profitable, bearing in mind that the reprocessing accounts for 85% increase of the total spent fuel and waste management costs.[95]

The Generation IV reactor project[96] seeks to develop next generation reactors without such problems. However, even if it is successful, commercial scale plants are not likely before mid-century. The budget allocation for this project is, for the time being, negligible[97] and is exclusively financed with public funds, which raises questions about the industry and governments' commitment to the future of nuclear energy, even on the long term. On the other hand, the US initiative Global Nuclear Energy Partnership (GNEP), whose objective was to develop new, proliferation-resistant, reprocessing technologies, has been abandoned by the new Obama Administration. [98]

Waste will continue to be a serious problem without solution in the coming decades. The abandonment of the Yucca Mountain waste repository project after many years of study and evaluation raises the question of which is the ultimate solution to this problem; a problem that is momentarily being resolved by storing spent fuel on-site in reactor pools or dry casks or at a centralised repository. This mitigates the CO_2 emission problem at the expense of another intractable environmental problem for which there is no remotely acceptable solution.

From the onset of the nuclear era to our days, it has always been assumed that, pursuant to calculations and fundamental technical considerations, high-level nuclear waste can be easily and safely disposed of in deep geological repositories. However, as the Yucca Mountain project has shown, and also the German study on the use of salt formations, or the tests carried out by France in Bure, we are still a long way off from establishing the safety of a deep geological repository somewhere in the world (Refer to Chapter 2.2).

For all of the above reasons, it would be very difficult, not to say impossible, for nuclear energy to offer a vital and timely contribution to reducing emissions.[99] Given the lead times required to rebuild the nuclear industry and deploy a large reactor fleet, and the urgent need to reduce emissions, we must consider prioritary the study of other non-carbon emitting sources of electricity generation that can be deployed more rapidly, more economically, and with fewer collateral problems.

It may be that we will have power plants with emission-capturing capabilities in the future; however, at present, the development of commercial scale plants with this type of technology before mid-century is mere speculation. The most plausible alternatives are therefore, on the one hand, higher energy savings and efficiency to reduce demand-side consumption, and, on the other hand, the use of renewable energies, in particular wind and solar.

95 *Spent Nuclear Fuel Reprocessing in France*, Mycle Scheneider & Yves Marignac, International Panel on Fissile Materials, April 2008, (http://www.ipfmlibrary.org/rr04.pdf)

96 http://www.gen-4.org/index.html

97 The proposed US budget for2010 allocates $191 million to Generation IV. (http://www.cfo.doe.gov/budget/10budget/Content/Highlights/FY2010Highlights.pdf)

98 *Green focus in US energy budget*, World Nuclear News, 8 May 2009. (http://www.world-nuclear-news.org/print.aspx?id=25192)

99 Refer, for instance, to *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change*, Brice Smith, IEER Press, 2006. (http://www.ieer.org/reports/insurmountablerisks/)

2.1.8 Criteria for an orderly closure plan of Spanish nuclear plants

As already stated above, and for a variety of reasons, it appears unlikely that the world nuclear fleet can be replaced over the next decades, and even less new nuclear investments which would contribute significantly towards reducing CO2 emissions. Even if the fleet were replaced, it appears unlikely that this is the most efficient option for reducing emissions today. Therefore, out of the two public policy options mentioned in the MIT report - large-scale expansion or closure at end of plant life - the latter appears to be more plausible.

The application of the precautionary principle advises therefore to provide for the inability to replace the nuclear fleet no extend the lifetime of existing plants beyond their design life, and plan for eventual migration to other generation technologies, in particular, renewable energies. Otherwise, we might find ourselves in the position of the US or the UK, who did not provide for these circumstances ahead of time, and are now making a virtue of necessity, extending the life of their power plants well beyond the normal lifetime, or are rapidly deploying gas plants to offset the loss of nuclear power generation capacity, in those cases in which extending the lifetime entails high risks or defeats the purpose, or to offset delays in new builds.

Extending the lifetime of power stations beyond 40 years entails various risks. Firstly, the possibility of a serious accident in a plant. An accident that would immediately advise the closure of all plants of similar design or age, leading to an enormous loss of generating capacity, which would surely cause supply shortages. Secondly, it appears likely that even without a serious accident, the availability of these ageing plants will decrease owing to a variety of incidents, causing, yet again, supply shortages. Lastly, the existence of a large nuclear capacity makes it difficult for renewable energy sources to be included in the power generation mix, obstructing the inevitable transformation of the electrical network.

It appears unlikely that this uncertainty will be resolved by 2020, given that the first power plant replacement plans in the US (perhaps four or five plants) and the UK (perhaps four plants) will be made known at that time

Spanish nuclear fleet

As shown in the following table, almost all the Spanish fleet, save for Garoña, has not fortunately surpassed half the design life, therefore, there is still time to plan an orderly replacement, provided advances are made in alternative renewable sources of generation, and in storage and demand management systems.

Table 2.1.1: Outlook of the Spanish nuclear park presuming a service life of forty years.

NUCLEAR POWER PLANT	DATE OF ISSUANCE OF CURRENT LICENCE	VALIDITY	DATE OF NEXT RENOVATION	Will have been functioning for 40 years
Santa María de Garoña	5/07/1999	10 years	July 2009	May 2011
Almaraz I	8/06/2000	10 years	June 2010	May 2021
Almaraz II	8/06/2000	10 years	June 2010	October 2023
Ascó I	1/10/2001	10 years	October 2011	December 2024
Ascó II	1/10/2001	10 years	October 2011	March 2026
Cofrentes	19/03/2001	10 years	March 2011	March 2025
Vandellós II	14/07/2000	10 years	July 2010	March 2028
Trillo	16/11/2004	10 years	November 2014	August 2028

Accordingly, whatever the future may have in store for the nuclear sector, the best option, at this point, is to plan the replacement of the fleet at the end of its design life with a mix of renewable energies and natural gas. In fact, by 2020, we will know whether the new generation of reactors announced by the US and the UK managed to meet industry expectations, and whether the experience gained from this first batch of reactors will enable the nuclear industry to undertake massive deployments once all major problems have been solved. In addition, we will also know whether the extension of the lifetime of existing US plants has not caused any problems.

If the situation in 2020 were favourable for the nuclear option, it would probably be advisable to extend the life of several existing plants beyond the design life, while new replacement facilities are under construction. Thus, it might be possible to deploy by 2030 a low-emission power grid based on renewables, nuclear and natural gas. This grid could be completely carbon-free before mid-century, to the extent that gas is gradually replaced by a mix of renewables and nuclear energy.

On the other hand, if, as seems most likely at the time of writing, the first batch of new reactors does not meet expectations or solve key concerns, there really is no other choice but to plan the closure of the plants and replace nuclear generation with a renewable-only system in 2050. In this scenario, and assuming, as has already been said, that the renewable energies deployed over the next 10 years equal, at least, current nuclear production, they could be completely replaced at the end of their lifetime. This would require natural gas to continue to play a significant role in the generation mix. If the life extension experience in other countries had been positive, we could even contemplate the possibility of further reducing emissions during the transition to a completely, carbon-free system by 2050.

The Case of Garoña

It does not appear advantageous to apply the wait-and-see and replacement strategies detailed above to Garoña power plant. In other words, its implementation would advise the closure of the plant on expiry of its operating license.

Garoña is the only first generation power plant still in operation in Spain after the closure of Vandellos I and Zorita. It was designed in the 1960s and came online in 1971. In fact, it can be considered almost a prototype, as General Electric, the manufacturer, modified the design several times in the following years. It has repeatedly developed corrosion cracks in several core elements of the reactor vessel over its 38 years in operation, without it being possible to halt the process, which can only be attributed to premature ageing. It has experienced several notorious incidents in recent months, after the last reload. The last incident seems to have been the breaking a fuel component, leading to increased radioactivity in the primary circuit.

Out of the total 7,700 MWe of the Spanish nuclear fleet, Garoña has a rated output of 460 MWe. Last year, its production represented 1.43% of the total net electricity generation of the Spanish grid. Its closure would therefore not have any impact on the coverage of Spanish energy demand. By way of illustration, Spain exported last year the equivalent of three times the electricity produced at Garoña. The increase in renewables fleet between 2006 and 2007 recovery alone accounted for double Garoña's production in that same year.

Thus, it may be considered that the efforts made in recent years deploying renewables has amply offset the closure of Garoña. The extension of its lifetime would therefore entail unnecessary safety risks. Its bearing on wholesale generation costs is negligible, and the potential increase in emissions, at certain hours, if it were replaced by a gas-powered generation plant would be amply offset by further deployment of renewables.

For all of the above, it would be advisable not to renew Garoña's operating license as a first step in the strategy of replacing nuclear capacity with renewable electricity, having deployed renewable energies in a timely fashion. A strategy, that as mentioned above we must continue, to pursue for the rest of the fleet in the event of an end-of-life closure without a possible or convenient replacement.

2.2 The cost of nuclear energy and the problem of waste [1]

2.2.1 Introduction[2]

The objective of this report is to examine whether nuclear power should be pursued as a means of reducing CO_2 emissions from the energy sector. Specifically, it is focused on the problems of radioactive waste, notably spent fuel, and of the cost and timeliness of nuclear in reducing CO_2 emissions compared to available low-or zero-CO_2 alternatives to coal-fired generation. Both European and U.S. experience have been used to exemplify the waste and cost issues.

Like Spain, the United States gets about 20 percent of its electricity from nuclear power. But, unlike Spain, which gets 11 percent of its electricity from wind energy alone, the United States gets only about 3 percent of its electricity from renewables (excluding large-scale hydro), about half of which is wind-generated electricity; the rest is geothermal and biomass. While solar energy is growing rapidly, it is still well under the one percent mark in the United States. About half of U.S. electricity comes from coal-fired power plants. About 20 percent of U.S. electricity generation comes from natural gas, most of it from combined cycle power plants. Spain gets about one-third of its electricity from combined cycle power plants.

There are three broad issues to consider in assessing whether to make a push for new nuclear power plants to address the problem of greatly reducing CO_2 emissions from the electricity sector:

- Radioactive waste, and specially spent fuel, management. If the CO_2 problem is reduced but only at the expense of creating a different and intractable environmental problem, radioactive waste disposal, it will be a poor solution.
- Factors in estimating the cost of nuclear power plants, including financial risk compared to alternatives that can be built faster and with lower risks.
- Cost of reducing CO_2 emissions using nuclear compared to alternative approaches for reducing carbon emissions – natural gas combined cycle and wind power plants.

So far as the economic analysis is concerned, it is important to note that this report is focused on comparative cost of reducing CO_2 emissions by replacing fully depreciated coal-fired power plants with alternative low or zero-CO_2 sources of electricity. In other words, it is intended to be an analysis of the relative costs of the various approaches in reducing CO_2 emissions and should be used primarily for that purpose.

1 The author of this chapter is Arjun Makhijani, Ph.D., President of the Institute for Energy and Environmental Research. He holds a Ph.D. from the University of California at Berkeley, where he specialized in controlled nuclear fusion. He has been involved in analyzing energy issues since 1970 and is the principal author of the first ever assessment of the energy efficiency potential of the U.S. economy (1971). He is the author of *Carbon-Free and Nuclear-Free; A Roadmap for U.S. Energy Policy* (2008).

2 The author would like to thank Professor Stephen Thomas of Greenwich University in the UK for his suggestions and many really useful review comments on drafts of this report. He would also like to thank Marcel Coderch for sending him Spanish cost and electricity data and for his suggestions. And finally, he would like to thank Peter Bradford for his review as well. Of course, the author alone is responsible for the contents and analysis in this report and any deficiencies that may remain.

2.2.2 Spent fuel management considerations

AIn the early days it was an article of faith almost, based on scant calculations and technical considerations, that high-level nuclear waste could be disposed of in deep geologic formations without much difficulty. At the time it was assumed that uranium was a very scarce resource. A corollary was that spent fuel would be reprocessed and that essentially all the fissile and fertile materials (U-235, U-238) in reactor fuel would be used up in the production of nuclear energy, increasing the life of the natural uranium resources by a factor of about 100.

These assumptions did not hold up well during the first half century of nuclear power production. Sodium-cooled breeder reactors proved not only to be very expensive, but turned out to be very difficult to master technically. Some prototype and demonstration plants worked well (such as EBR II in the United States for instance), while others had early failures (EBR I, Fermi I, Monju[3]) and yet others proved too difficult to operate consistently Superphénix[4]) Monju is not definitively closed yet, it is in long-term shutdown. Another demonstration breeder, the Dounreay Prototype Fast Reactor (250 MWe) built in Scotland which went on line in the mid-1970s was in the difficult-to-operate category, with a lifetime capacity factor was 23%.[5] The cost of decommissioning is estimated to be $6 billion, amounting to $2,400 per kW for decommissioning alone!

LThe result of the failure of breeder reactor technology to come to technical and economic maturity is that almost the entire waste stream remains to be managed even in the country that has the most extensive plutonium (mixed oxide) fuel use – France. Only about one percent of the recovered materials at the reprocessing plant at La Hague have actually been reused as fuel. And France has generated added radioactive wastes contaminated with plutonium and other transuranic radionuclides to concentrations high enough to require them to be disposed of in a deep geologic repository along with vitrified high-level waste. The U.S. Department of Energy (DOE) estimates that the volume of high-level and transuranic radioactive wastes to be disposed of in a repository as a result of the use of a reprocessing cycle in thermal reactors would be about six times the volume of direct disposal of spent fuel. [6]

It has also turned out to be more complex than imagined to dispose of spent fuel in salt, the geologic medium originally considered the best for disposal of radioactive waste. A recent draft rule published by the U.S. Nuclear Regulatory Commission states as follows:

> "Salt formations currently are being considered as hosts only for reprocessed nuclear materials because heat-generating waste, like spent nuclear fuel, exacerbates a process by which salt can rapidly deform. This process could potentially cause problems for keeping drifts stable and open during the operating period of a repository." [7]

3 The Monju reactor went critical in 1994 and had a sodium fire in the secondary loop in 1995. It was restarted in 2009.

4 For a history see Arjun Makhijani, *Plutonium End Game: Managing Global Stocks of Separated Weapons-Usable Commercial and Surplus Nuclear Weapons Plutonium*, Institute for Energy and Environmental Research, Takoma Park, January 2001.

5 FR data are from Professor Steve Thomas, personal communication, 6 May 2009.

6 U.S. Department of Energy, Office of Nuclear Energy, *Draft Global Nuclear Energy Partnership Programmatic Environmental Impact Statement*, GNEP PEIS; DOE/EIS-0396, October 2008, links at http://nuclear.gov/peis.html; hereafter PEIS 2008, Table 4.8-6, p. 4-189. See thermal reactor recycle, Option 1. Comparable French data that separate reprocessing and reactor wastes are not readily available.

7 U.S. Nuclear Regulatory Commission. "Waste Confidence Decision Update," Federal Register v. 73, no. 197, October 9, 2008, pp. 59551 to 59570. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-23381.pdf. Hereafter referred to as NRC 2008.

In other words, the operational period of a salt formation could be problematic, a consideration that has been borne out by some of the troubles experienced by the Gorleben site in Germany.[8]

Second, reprocessing has turned out to be more-proliferation prone and expensive than acknowledged during the days of greater enthusiasm for that technology. The surplus plutonium in the commercial sector today rivals that of all the weapons plutonium in the nuclear warheads of all nuclear weapon states combined.

Third, reprocessing is polluting the oceans with radioactivity; France and Britain discharge large amounts of radioactively contaminated liquids into the English Channel and Irish Sea (respectively), contrary to the wishes of most parties to the Oslo-Paris Accord.[9]

Largely as a result of the problems that emerged with reprocessing and breeder reactors and the fact that uranium turned out to be more plentiful than imagined in the 1950s, most countries turned to direct disposal of spent fuel in deep geologic repositories as their main waste management policy. Of course, as noted, reprocessing only increases the volume of waste to be disposed on in a deep geologic repository.

About two dozen countries have made declaratory statements that deep geologic disposal is a suitable means for disposing of spent fuel. But statements have turned out to be easier to make than providing a convincing demonstration that deep geologic disposal can occur while demonstrating with some confidence that it can be done safely – that is, according to some defined norms of radiation protection comparable to the present. In fact, decades of investigation and billions of dollars in expenditures have shown that such statements of safe are very difficult to prove, given long-term uncertainties. The U.S. and French repository programs are very important examples of the kinds of problems that have emerged in the course of investigations of geologic isolation of spent fuel and high-level radioactive waste.[10]

As a preliminary to the specifics in the United States and France, it is important to consider that three official terms are important:

- There should be a "reasonable assurance" that disposal can be safely done.
- There should be a definition of "safe disposal", and
- There should be a scientific demonstration that safe disposal with reasonable assurance is "technically feasible" for the lengths of time involved.

A. The United States Geologic Repository Program

Corrosion of the metal canisters has been a critical problem in assessing the suitability of Yucca Mountain as a deep geologic repository. While the DOE believes that certain corrosion problems are insignificant, other researchers have concluded that the problem is fatal to the DOE's design of an unsaturated repository – that is a repository above the water table that has water vapor and air in the rock pores.

8 See for instance Bernd Franke and Arjun Makhijani. *Avoidable Death: A Review of the Selection and Characterization of a Radioactive Waste Repository in West Germany*. Washington, DC: Health & Energy Institute; Takoma Park, MD: Institute for Energy and Environmental Research, November 1987.

9 Britain may shut its reprocessing operations in the next few years.

10 The following paragraphs are adapted from Arjun Makhijani, C*omments of the Institute for Energy and Environmental Research on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storag*e, Institute for Energy and Environmental Research, 6 February 2009. Hereafter referred to as Makhijani 2009.

DOE proposes disposal in the unsaturated zone in a configuration in which boiling of water is expected for "the first few hundred years after closure…in the drift vicinity."[11] The DOE expects the effects to be as follows:

> "Thermal expansion of the rock matrix induces thermal stresses and associated changes in flow properties near emplacement drifts…. Thermally-driven effects also cause dissolution and precipitation of minerals, which may affect flow properties (thermal-hydrologic-chemical effects)." [12]

While the DOE believes that these processes will not prevent satisfactory repository performance, Dr. Don Shettel, an expert geochemist and consultant for the State of Nevada, has concluded that a hot temperature design is "fatally flawed." [13] This was extensively discussed at the May 18, 2004, meeting of the U.S. Nuclear Waste Technical Review Board (NWTRB):

> "We've talked about thermal concentration of brines and boiling point elevation. We can get fingering of concentrated solutions in fractures, thereby increasing the probability and percentage of thermal seepage waters that might reach the drift on the EBS [Engineered Barrier System]. We have mixed salt deliquescence [absorption of water vapor by solid salts so as to dissolve them], not so much from the dust that's on the canisters, but from the increased amount of thermal seepage water that we believe can reach the EBS. And, if these evaporated or concentrated solutions can reach the EBS before the thermal peak, then they can become, even after the thermal peak, get hydrated salts with thermal decomposition, with the evolution of acidic solutions and vapors. And, one of the most important aspects of this model is the wet-dry cycling or intermittent seepage. If you get some seepage on the canisters, and it evaporates to some extent, dries out, the addition of water to that can generate acid.
>
> …We believe that the high temperature design for the repository is fatally flawed for the number of reasons that I've discussed, and that emplacement in the saturated zone would be much better, because that's essentially where DOE has tested their metals at. And, the saturated zone is also the much less complicated in terms of processes and modeling" [14]

There is experimental evidence that wet-dry cycling at Yucca Mountain could result in very rapid corrosion of the C-22 alloy containers. While the DOE believes the contrary, Dr. Roger Staehle, who worked as a consultant for the State of Nevada with a research team including other experts and Catholic University of America faculty, made a presentation to the NWTRB during which he went through the team's experimental findings for the NWTRB; he concluded with a set of stark "warnings".

> Warnings:
>
> 1. There is an abundance of warnings as well as solid quantitative data that demonstrate that corrosion of the C-22 alloy is inevitable and rapid.
>
> 2. A good paradigm for the warnings about C-22 can be found with Alloy 600 that was widely used in the nuclear industry as tubing in steam generators and as structural components. Alloy 600 has broadly failed in these applications, and present failures could easily have been predicted from past occurrences.
>
> 3. There are now abundant warnings that that C-22 alloy is not adequate nor is the present design of the repository adequate. Such warnings are founded on warnings, some of which are 15 years old.
>
> 4. Further, there is abundant evidence that the YM site itself is not adequate.

11 DOE 2008 p. 2.3.3-58 in Chapter 2.

12 DOE 2008 p. 2.3.3-58 in Chapter 2.

13 Don Shettel is Chairman and Geochemist, Geoscience Management Institute, Inc.

14 Shettel 2004.

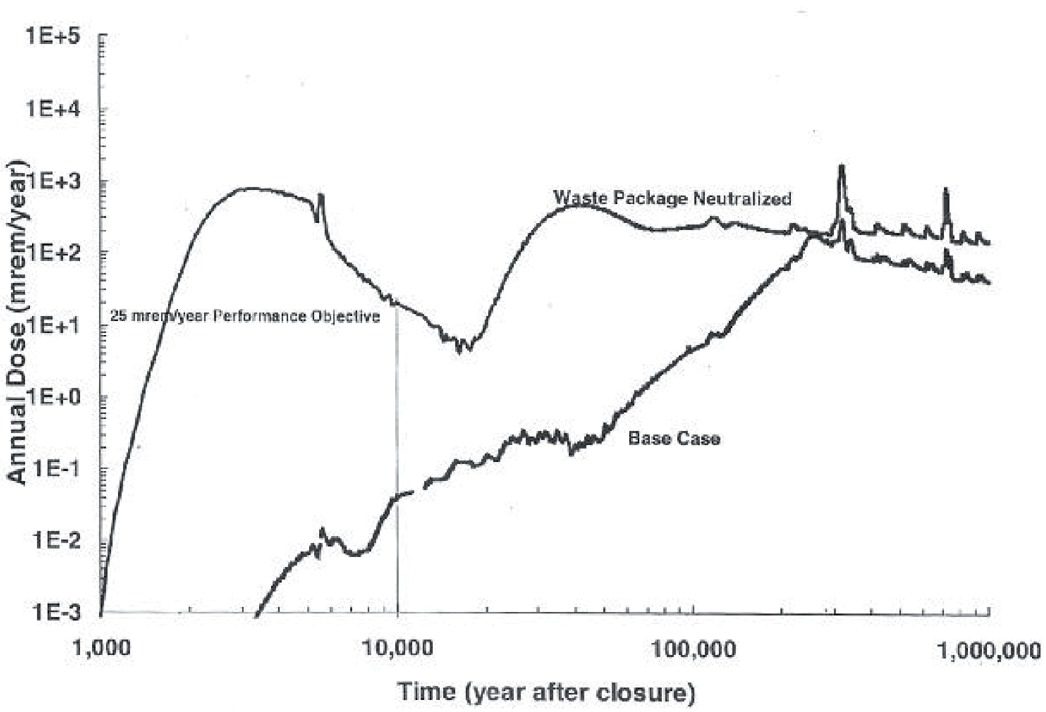
5. The analogies of warnings from the present nuclear industry are abundant and apply directly to whether the present design at YM is adequate. The answer is that it is not.

6. Some of the warnings from experience of the water cooled nuclear reactor industry apply directly to the design and development of the Yucca Mountain facility. These should be carefully assessed, e.g. as they apply to heated surfaces.

7. Finally, the incapacity to inspect the YM containers requires assurances of reliable performance that are higher than those of normal industrial expectations.[15]

The NWTRB urged the DOE to include consideration of deliquescence-induced corrosion in its license application to the Nuclear Regulatory Commission.[16] The DOE rejected this advice, saying that such corrosion would be "insignificant".[17]

Chart 2.2.1 : Radiation dose effect of neutralizing the waste package.



Source: U.S. DOE Office of Civilian Radioactive Waste Management, Design Selection Process, " presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999. Presented by Dennis C. Richardson. Online at http://www.nwtrb.gov/meetings/1999/jan/richardson.pdf.

15 Staehle 2004.

16 U.S. Nuclear Waste Technical Review Board. *Report to The U.S. Congress and The Secretary of Energy: March 1, 2006-December 31, 2007*. Arlington, VA: NWTRB, [2008]. On the Web at http://www.nwtrb.gov/reports/nwtrb_2007_web_508.pdf, pp. 27-28.

17 U.S. Department of Energy, Office of Civilian Radioactive Waste Management, *Safety Analysis Report: Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 0, Las Vegas, NV: OCRWM, June 2008. Links on the Web at http://www.nrc.gov/reading-rm/adams/web-based.html, searching for ML081560400, p. 2.3.5-12.

The controversies surrounding Yucca Mountain have been so serious that President Obama declared the site unsuitable during his campaign and he has been supported in this by Energy Secretary Chu, who is a Nobel-Prize-winning physicist. The above graph, produced by the DOE itself, shows that the only element of the isolation system that would contribute substantially to waste isolation is the metal container – and that is the very element that some researchers believe is the fatal flaw in the entire repository design! The Figure shows that if the waste package is removed, the containment of the waste is projected to be very poor and doses are expected to be high.

We support the development of a geologic repository program in the United States, but my opinion, Yucca Mountain is the worst site that has been investigated there. As a result of a number of technical, scientific, design, institutional, and political problems, the Yucca Mountain program is on the brink of failure. A new inquiry commission on nuclear waste is to be formed and it appears likely that the whole process will have to begin from "square one" again though about ten billion dollars of ratepayer money has been spent already and over a quarter of a century ahs gone by since the Nuclear Waste Policy Act was passed in 1982. That law led to the investigation of a number of sites between 1982 and 1986. The search was narrowed to a single site by a revision of the law in 1987, rather than by the process of screening and site characterization that was envisioned in the 1982 Act. In the meantime, the U.S. government is in breach of its contracts with nuclear utilities to begin taking charge of the wastes as of January 31, 1998. Court-ordered damage payments against the government are mounting by the year. The poor, politicized process that was supposed to hasten the development of the repository has, instead, turned into a much more prolonged and costly process due to its underlying scientific deficiencies and the greater political turmoil that bypassing sound science, among other things, has caused.

It is to be noted that the other top sites investigated in the United States have also had their problems. One was a salt site, which is the type of formation not now being considered by the NRC for spent fuel, as noted above. The third top site selected in the 1980s before research was confined to the single location of Yucca Mountain was the basalt formation at the Hanford, Washington site. Many serious defects of the site, including very serious problems in safety, were noted by one of the leading geologist in the United States, Donald E. White, who was a member of the National Research Council panel that wrote a report for the DOE on geologic isolation. In regard to safety Dr. White noted three "threatening effects" including "rock bursting," "costly and troublesome drainage problems" and the following:

> "Construction of the repository at very high in-site temperatures, estimated by Rockwell to be 57oC but possibly considerably higher. Refrigeration on a scale seldom if ever attempted in world mining may be necessary. The costs in time, money, energy, and lives of men are likely to be very high.
>
> Even if each of the above [threatening effects] is individually tractable, all in combination may be intolerable. More satisfactory alternatives probably can be found elsewhere"[18]

Yet, the DOE ignored this 1983 analysis and went ahead and selected basalt at Hanford as one of the top three sites it would characterize.

A large part of the problem in the United States is that political expediency has tended to dominate the process of site selection and characterization. Once that occurs, the temptation to overlook or downplay critical problems to the point of failing to fully investigate them is great. Political pressures to ignore problems have been so strong that when it was found that Yucca Mountain may not meet environmental standards, Congress simply ordered the development of new standards that would be specific for Yucca Mountain. Similarly, when the NRC found that Yucca Mountain may not meet its technical performance criteria for repositories, it simply revised its technical criteria. [19]

18 White 1983, p. 25, reprinted as an appendix to Makhijani and Tucker 1984.

19 Makhijani 2009, pages 11 to 13.

B. The Bure repository project in France

The results of the French repository investigation also illustrate some of the same problems, such as failure to include experiments that are suitable for demonstrating performance. For instance, an expert team of geologists put together by IEER concluded that both the thermal and mechanical aspects of the research designed to study the suitability of the French repository location were deficient in essential respects, despite the fact that the program had many strong points:

> "A crucial problem for research is that the model must estimate performance not of the natural setting but of a geologic system that has been considerably disturbed by a large excavation, which may induce fractures not originally present, by the introduction of (thermally) hot wastes, and by the addition of various backfill materials and seals. Hence, the system being modeled is no longer the original geologic system, but a profoundly perturbed system. .... Estimation of performance of a system under these conditions with some confidence poses challenges that are, in many ways, unparalleled in scientific research.
>
> In the specific case of the Bure site, the host rock is argillite, a hard rock consisting of clayey minerals, carbonates (mainly calcites), and quartz. The in-tact rock is not very porous, leading to expectation of diffusive flow in the absence of fractures and in the absence of disturbance by mining. Such flow would be very slow and the expected travel time of radionuclides released from waste packages could be very long.
>
> However, the IEER team's evaluation of (i) the documents, (ii) argillite rock properties under conditions of heat and humidity, and (iii) the research done to model the site performance indicated that the actual conditions prevailing in an actual repository could be very different from diffusive flow. Failure of certain components, notably repository seals, could result in rapid (in geological terms) transport of radionuclides to the human environment.
>
> ANDRA's own estimate of dose under conditions of seal failure was higher than the allowable limit of 0.25 millisieverts (25 millirem) per year. In this context, IEER concluded that ANDRA's scenario for human exposure was not necessarily conservative, in that doses to an autarchic farmer family (also called "subsistence farmer family") using groundwater in certain locations could be even higher than the dose at the surface water outcrop estimated by ANDRA". [20]

Note that as of the date of the IEER report on the Bure site in France, ANDRA's own estimate of dose exceeded its regulations in the event of seal failure. In this context, research on characterizing the long-term integrity of seals becomes critically important. And IEER found ANDRA's research program in this very area to be deficient. One of its principal conclusions about the research on seals was that it seemed to of "marginal value" and was far from adequate to enable a sound determination of repository performance:

> "One crucial problem is that the simulated slot sealing test in the underground laboratory may be of marginal value and utility. The test is planned to be done very early on after excavation and only over a very short period of time relative to the duration of performance requirements and even relative to the time lapse over which the actual EDZ [Excavated Damaged Zone] will develop, prior to seal installation. This is neither convincing nor satisfactory. It is difficult to see how and why increasing the stress component parallel to the gallery walls will reduce the permeability in that direction or how a flatjack can simulate a bentonite seal, except in the most crude of approaches". [21]

20 Makhijani and Makhijani 2006. Italics in the original. This article is based on the full report, which is in French: *Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue : Rapport Final.* Hereafter cited as IEER 2005. The qualifications of the team members are found in Attachment C.

21 IEER 2005, p. 59, in Chapter 2. Retranslated from the final French report by Annie Makhijani.

Here again we found that critical tests required to properly assess the performance of the seals were not part of the repository characterization program. A related issue that came to light during the evaluation of the repository research program in France was that in case of a failure of the seals, ANDRA, the agency responsible for repository development, estimated that the radiological protection standards would be greatly exceeded. Calculated peak doses in that scenario due to chlorine-36 in Class B waste (the approximate equivalent of U.S. Greater Than Class C waste) would be 300 millirem per year and those due to iodine-129 in spent fuel would be 1,500 millirem per year.[22] Both of these are greatly in excess of the French limit of 25 millirem per year and even of the more lax U.S. final EPA standard for Yucca Mountain of 100 millirem per year beyond 10,000 years.

C. Potential lessons for Spain – new reactors and relicensing existing reactors

One of the problems that has emerged as a result of the difficulties of actually characterizing and completing a repository development program is that nuclear waste has to be stored on site for many decades longer than originally anticipated. In its proposed draft rule on "waste confidence", the NRC has suggested that a repository may not be available until 50 to 60 years after the expiry of the license of the last reactor, without even specifying which generation of reactors it was talking about.[23] Hence, after having previously stated that a repository would be available by 2020, the NRC now proposes no fixed date for commencing disposal. This means that waste would have to be stored at reactor sites for a 100 to 150 years and perhaps much longer than that. Further, if reactors continue to be re-licensed, as they are being currently in the Untied States, spent fuel pools cannot be emptied. Fresh spent fuel must be stored in such pools for five to seven years before it can be moved to dry storage. Spent fuel pools are the most vulnerable to accident and terrorist attack compared to dry storage and much more vulnerable compared to dry hardened storage of spent fuel. Despite this, the NRC has not required the emptying of the pools to the extent possible, but instead allows re-racking – that is more dense packing of the pools – increasing the risks and consequences of problems or attacks. Finally, the NRC has not ordered hardened on site storage, which would decrease the consequences of a terrorist attack by making dry storage canisters and storage more resistant to damage in case of such an attack.

Spain is fortunate in that it so far has only eight operating power reactors accounting for only about 8.5 percent of its installed capacity. It has combined cycle power plants that operated at less than fifty percent capacity factor in 2008. This capacity could be used more intensively to replace nuclear generated electricity for part of the year during the period when renewables are ramped up more rapidly. Spain has a large renewable energy industry in both the wind and solar sectors. By phasing out nuclear power, Spain can plan hardened on-site storage to make its population as safe as possible from the risks of extended on site storage. So long as spent fuel pools exist – that is so long as reactors are operating, risks to surrounding populations and to future generations who might live in those areas will remain significantly higher than they need be.

Further, if Spain keeps the total amount of its spent fuel to a modest amount and embarks on a policy of phase out of its reactors a strategy of joining with countries, such as Germany, that have also decided to phase out nuclear power may become viable for repository development. If Spain relicenses existing reactors and builds new ones, the need for a domestic repository program will grow; along with it the social controversy and conflict are almost certain to grow as well. One of the most important problems that has not received due attention in this regard is the loss of focus on the problem of actually getting rid of fossil fuels from the energy system. Nuclear requires not only a disproportionate amount of financial resources to develop, it also requires a hugely disproportionate amount of a society's political resources to manage the social conflicts that go with it.

22 ANDRA 2001, p. 139.

23 NRC 2008, Proposed Finding 2.

Finally, a decision not to re-license the Garona reactor, and old, smallish plant of less than 500 MW that has operated for 40 years, will not greatly affect the CO2 emissions situation, since no other operating license is due to expire in Spain in the near future. Simply continuing the recent shut down of the reactor would allow room for the kind of debate on Spain's energy system to occur without the distraction of a short-term issue. In other words, Spain is in the fortunate situation of being able to decide its energy future and its global role in a twenty-first century energy system without being encumbered by pressing short-term issues that would be a distraction from the larger economic, security, environmental, and industrial questions that need to be decided in all major countries.

In sum, there are substantial reasons, connected to

- immediate waste issues,
- security,
- planning and implementing the safest possible on-site storage, and
- holding a clear-eyed debate about the future of Spain's energy system without short-term distractions.

2.2.3 Economics of nuclear power plants based on current U.S. data [24]

This section provides an assessment of the costs of nuclear power plants and discusses the financial risks, costs of delay and other uncertainties and cost factors that have been associated with much of the nuclear development in the past. Present experience in the West appears to be reproducing these old patters. We will refer both to U.S. and European examples. The U.S. experience, where private investment dominates the electricity sector, may be especially relevant for Spain, where the electricity market is also largely liberalized.

A. The United States

At the present time, some privately owned utilities have made estimates of nuclear power costs in the process of applying for permits to build the plants. While they have also made applications for government subsidies, the utility assessment of costs prior to subsidies provides a suitable basis for estimating nuclear power costs in a way that can be compared with unsubsidized costs of renewable electricity.[25]

A number of estimates have been made since late 2007, when applications began to be filed with Public Utility Commissions and some companies started to make public announcements about expected costs. These estimates vary widely. Moreover recent estimates (late 2007 to present) are much higher than earlier estimates due to rapid cost escalation in the construction sphere and especially in large scale power plants, including coal and nuclear plants but also wind and natural gas fired power plants. Only solar electricity costs have been declining.

Rapid cost escalations have made it difficult to make precise cost forecasts. The most reliable estimates come from regulated utilities, which must make declarations to regulatory bodies so as to be able to recover their costs from ratepayers. Such estimates have been made by updating and converting experience in Japan and South Korea in the early part of this decade and the last decade to U.S. conditions, with appropriate cost escalations.

24 This section is adapted from Arjun Makhijani and the Sustainable Energy and Economic Development (SEED) Coalition, *Nuclear Costs and Alternatives*, April 2009.

25 Renewable electricity costs for Spain are not estimated in this section.

The most detailed estimate of the capital costs of nuclear power were presented in a late-2007 filing with the Florida Public Service Commission by Florida Power and Light.[26] This filing contains a detailed breakdown of the overnight costs of a commercial nuclear reactor as well as estimates for cost escalation during construction and interest costs incurred during construction. The cost estimated for a 2,200 megawatt project with two reactors of 1,100 MW each ranged from $12.1 billion to $17.8 billion, yielding a per kilowatt cost range of $5,492 to $8,071. A larger two-reactor project (3,040 MW) was estimated to cost $5,426 to $8,005 per kW. These include transmission $300 costs of about per kW (including interest and inflation during construction of the transmission lines), which should be deducted to yield a comparison based on busbar costs. The FPL estimates indicate that a reasonable middle figure to use (in the absence of delays) for capital cost would be about $6,400 per kilowatt.

Other estimates are higher. Puget Sound Energy has made a cost estimate of $10,000 per kW.[27] Progress Energy, which has proposed a two-reactor (AP 1000) project in Florida, Progress Energy's project cost estimate in 2008 was $17 billion, including $3 billion for transmission. Excluding the transmission investment, the cost per kW works out to about $6,360 as initially estimated. [28]

The cost of some of these projects are so high that the CEO of General Electric, who supports nuclear energy since his company is trying to get a new reactor design certified, told the Financial Times in November 2007 that if he were the CEO of an electric utility, he would not order a nuclear plant:

> "If you were a utility CEO and looked at your world today, you would just do gas and wind...You would say [they are] easier to site, digestible today [and] I don't have to bet my company on any of this stuff. You would never do nuclear. The economics are overwhelming". [29]

The main point of the comment, of course, is that natural gas and wind are much less risky. Moreover, both can be built more rapidly in smaller increments, making them less vulnerable mis-estimation of future electricity demand.

Wall Street has made similar estimates of the cost of new nuclear power plants. For instance, Moody's estimated the cost of new plants at $5,000 to $6,000 per kW. [30]

In sum, a reasonable range for U.S. estimates of new nuclear plants, based on company filings with regulators as well as Wall Street estimates is $5,000 to $8,000 per kW, excluding the cost of delays, defaults on loans, and other risks associated with long-lead time capital intensive projects at a time of economic uncertainty. It should be noted that since no reactors have actually been built or have even been licensed to be built for a long time (all reactors ordered after October 1973 were cancelled and the last completed reactor was brought on line in 1996), there is a large uncertainty in these costs simply form lack of recent U.S. experience. This has also been noted on Wall Street, which is reluctant to finance these plants without federal loan guarantees. Indeed companies are reluctant to build them without those guarantees.

26 FPL 2007.

27 As cited in Jim Harding. *Nuclear Power 2008* Harding Consulting. Power Point Presentation presented at the *Bulletin of Atomic Scientists' Conference on the Future of Nuclear Power,* including supplemental slides, Chicago, Illinois, September 25, 2008. Hereafter referred to as Harding 2008. Jim Harding was part of the 2007 Keystone study and did much of the economic work for that study. The Keystone study was cited in TVA 2008. Mr. Harding is also a consultant on nuclear energy costs to the National Research Council.

28 John Murawski, "Nuclear reactors' cost: $17 Billion: Progress Energy plans to file its estimate for two new reactors with Florida regulators today", *News and Observer*, 11 March 2008.

29 Jeffrey Immelt, as quoted by Sheila McNulty and Ed Crooks, "U.S. Utilities Sceptical over Nuclear Plants," *Financial Times*, November 18, 2007. Italics added; bracketed information supplied by FT authors.

30 New Nuclear Generation in the United States: Keeping Options Open Vs Addressing and Inevitable Necessity, October 2007, p. 11.

A range of $5,000 to $8,000 per kW corresponds to 4,300 to 6,300 euros per kW (rounded at 1.17 dollars per euro. [31]

B. Europe

There are two reactors under construction in Europe. Both are EPRs. The one in the more advanced stage of construction is the Olkiluoto reactor in Finland. The original cost was estimated at 3.2 billion euros, or 2,000 euros per kW. There have been repeated delays and cost escalations. The delay at present is estimated at 3 years and the cost escalation is over 50 percent. The present cost therefore stands at about 3,000 euros per kW.

It is unlikely that the delays and cost escalations are over (see below).

C. The Costs of Delay

Delays have been and continue to be typical of relevant nuclear reactor construction experience in the West. The longest instance in the United States was the TVA Watts Bar project. Construction of TVA's Watts Bar reactor project started in 1973; the completion date was 23 years later in 1996. [32] As another example, the Comanche Peak Unit One, in Texas, had a planned construction period of 5 years, but took over 11? years to build, a 6? year slippage. [33] Comanche Peak holds the dubious distinction of being the most expensive completed nuclear power project built in the United States.[34] The 1975 definitive cost estimate (DCE) was $978 million, but the actual cost was $7.8 billion, a 690 percent cost overrun.[35] The total project cost, including capitalized financing charges, Allowance for Funds Used During Construction, was 140 percent above the average total for multi-unit nuclear power plants build during the 1980's.[36]

The Dungeness B reactor in the UK took a comparable amount of time.[37] The Olkiluoto reactor's turnkey cost has been obsolete for some time. But recent days portend a new and more difficult phase, since fundamental safety issues have arisen about the reactor that portend higher costs and more delays.

The brief present experience in Europe and the United States appears to be repeating this unfortunate pattern. The most ominous note has perhaps been sounded regarding the AREVA project in Finland. On December 9, 2008, the head of the Finnish regulatory agency, STUK, wrote to the CEO of AREVA, the reactor vendor, that basic safety issues were not being addressed:

> "Dear Mrs. Lauvergeon,
>
> With this letter I want to express my great concern on the lack of progress in the design of Olkiluoto 3 NPP automation.

31 An exchange rate of 1.17 dollars per euro is used throughout this report. It is the original issuing rate of the euro and also corresponds approximately to purchasing power parity. Exchange rate volatility is one of the uncertainties in nuclear power costs.

32 TVA website at http://www.tva.gov/sites/wattsbarnuc.htm

33 Clarence Johnson, Costs of Current and Planned Nuclear Power Plants in Texas, A Consumer Perspective, CJEnergyConsulting, Austin, Texas, [March 2009]. Page 19. Hereafter Johnson 2009.

34 Ibid. Pg 14

35 Ibid. Pg 16

36 Ibid. Pg 14

37 Steve Thomas, personal communication, 6 May 2009.

The construction of Olkiluoto 3 plant seems to proceed generally well but I cannot see real progress being made in the design of the control and protection systems. Without a proper design that meets the basic principles of nuclear safety, and is consistently and transparently derived from the concept presented as an annex to the construction license application, I see no possibility to approve these important systems for installation. This would mean that the construction will come to a halt and it is not possible to start commissioning tests". [38]

Changes in or updates to the design, delays in testing and commissioning will all lead to higher costs. Moreover, the delay means that the Finnish utility, TVO, will have to purchase electricity from sources that emit carbon dioxide. As a result it faces substantial costs related to power purchases and CO_2 permits under its Kyoto Protocol commitments. An even more important problem may be that the energy-intensive industries that had been counting on cheap power based on 2,000 euros per kW will now have to purchase power on the open market, which may be far more costly to them and to the Finnish economy. TVO has filed a lawsuit claiming 2.4 billion euros in compensation from AREVA and Siemens.[39]

In the United States delays are occurring even before reactor construction has begun. Progress Energy had been counting on pouring concrete before securing a construction license. The NRC has denied permission to do this. A 20-month delay has been announced.[40]

According to the Florida Power and Light study cited above, a delay of a year could add between $800 million and $1.2 billion to the capital cost in a 2,700 MW project due an increase in the Allowance for Funds Used During Construction.[41] Reactor projects in the United States have experienced delays ranging from a short period to decades. A several-year delay could therefore increase the cost by billions of dollars.

Another aspect of delays that is likely to become more costly in the future is that utilities that have CO_2 -emitting generating plants will have to pay to acquire the CO_2 permits to keep them in operation during the period of delay. At 40 euros per metric ton of CO_2, operating a coal-fired power plant for an additional year would impose an added cost of 300 euros per kW. For an EPR, this would amount to 480 million euros per year.

D. Financial risks associated with nuclear power

High capital costs are only one part of the financial risk of nuclear power. The long lead times, even in the absence of delays, is a major risk factor, and delays, which are often likely, add to this problem. Successful investing in high capital costs projects requires reliable demand forecasts for electricity. Yet, long lead times mean that a forecast must be reliable about 10 years or more from the date of significant expenditures on planning and half a dozen years from the start of construction, even in the absence of delays. This is one of the risk factors associated with long lead times.

As another example of greater financial risk associated with long lead times, there could be cost escalations during the planning and construction periods, with the latter being particularly problematic. According to estimates by Jim Harding, a former utility executive, cost escalation between zero and 14 percent per year

38 This letter, which was recently leaked to the press, has been posted on the Greenpeace website at http://weblog.greenpeace.org/nuclear-reaction/2009/05/problems_with_olkiluoto_reacto.html

39 Helsingin Sanomat, "TVO seeks EUR 2.4 billion in damages for Olkiluoto nuclear reactor delays," April 4, 2009, at www.hs.fi/english/article/TVO+seeks+EUR+24+billion+in+damages+for+Olkiluoto+nuclear+reactor+delays+/1135243097398

40 "Progress Energy Delays Nuclear Power Plant," 1 May 2009, Power Group Online Article at http://pepei.pennnet.com/display_article/360918/6/ARTCL/none/none/1/Progress-Energy-delays-nuclear-power-plant/

41 FPL 2007, p. 52.

increases the costs from 10.7 cents per kWh to 23 cents per kWh, when variation in the overnight costs is also taken into account'.[42]

As another risk factor, forecasts of demand in a rapidly changing economic environment are very difficult. Since new power plants, whether nuclear or solar and wind with storage are likely to result in electricity that is more expensive on average than current generation costs, there will likely be a demand response. This occurred in the mid- to late-1970's in the United States, when the rate of electricity growth relative to the rate of economic growth declined sharply from the period prior to the onset of the energy crisis in 1973. As a result many reactor projects were cancelled during that energy crisis. In fact, all reactors ordered in the Untied States after October 1973, the date of the onset of the first energy crisis, were cancelled, in large measure due to the failure of utilities to anticipate the consistent long-term reduction in growth rate of electricity per unit of GDP growth.

The present situation is quite similar. Commodity prices have recently been even more volatile than in the crisis from 1973 to the mid-1980's. The risks of cancellation of new nuclear power plants, which have very long lead times compared to combined cycle natural gas plants, wind, and solar (of any type) are serious. Costing of nuclear power plants needs to include both the cost of delays and the risk that the plant may not be completed for a variety of reasons, including the possibility that demand may be lower than projected.

The combined risks of large capital costs, long lead times, and possible increases in costs due to delays is reflected in the reluctance of utilities to go to banks or to equity markets to raise the capital to finance new nuclear plants and the reluctance of Wall Street in turn to provide that financing. In fact, no new nuclear plant that has been proposed in the United States is planned to be financed by any traditional combination of equity and bond financing. But an estimate of the costs can be made if we compare nuclear financing to high risk bonds (popularly known as "junk bonds" also called "high yield" bonds). In recent months, the premium over long term U.S. Treasury bonds in a turbulent economic time can be 15 to 20 percent. For instance, according to Fortune, the rates on junk bonds soared to 20 percentage points above those on Treasurys" towards the end of 2008 before easing off by a few points.[43] Hence, financing nuclear power plants in the absence of federal loan guarantees could mean interest rates of 20 to 25 percent.

If we use the high risk rates to approximate the real-world inability to obtain free market financing (even prior to this crisis), then the risk-informed capital cost per kWh of nuclear power would be much higher than that estimated by a calculation that ignores that risk. It is likely that no power plant could be financed on the open market with such high prospective interest rates; nor would any prudent company seek such financing. And the facts on the ground support this view, since all proposals to build nuclear power plants in the United States involve federal government loan guarantees of advance payments from ratepayers towards capital costs during construction ("Construction Work in Progress" or CWIP), or both. In other countries where nuclear is making more inroads, such as China and India, this is occurring only because of very strong state support. It is also interesting to note that France's nuclear transformation occurred entirely when its utility, EdF was 100 percent government-owned; it is still 84% owned by the French government.

While there are no CO_2-emission-related risks associated with new nuclear power plants (or renewable energy sources), there are two other risks of high CO_2 costs associated with nuclear power plants.

First, since nuclear power plants take much longer to build than solar or wind power plants, or combined heat and power systems or projects to increase efficiency, using nuclear power involves additional CO_2 emissions during the period of construction compared to incrementally increasing zero- or low- CO_2 capacity (including

42 Harding 2008.

43 Mina Kimes, "There's Still Juice in Junk Bonds, *Fortune*, February 18, 2009, at http://money.cnn.com/2009/02/17/magazines/fortune/kimes_junkbonds.fortune/index.htm

efficiency). Delays in nuclear power plants would also increase CO_2 costs in terms of added costs of acquiring CO_2 emissions allowances of payment of added taxes. A $50 per metric ton of CO_2 cost could add hundreds of millions of dollars to the annual operating cost of a utility, depending on the mix of generating sources from which the make-up power is purchased during the delay.

Overall, it is reasonable to assume that the charge per kWh for new nuclear plants could range anywhere from about 7 U.S. cents per kWh to 15 cents or more per kWh (about 6 to 13 euro-cents per kWh, rounded), though the low end of this range may be unrealistically optimistic. This would reflect the potential range of costs, except in the case of cancellation, delays of many years, or severe real cost escalations during construction, all of which have occurred with some frequency in the past.

E. Cost escalation during construction

We have briefly illustrated the problem of cost escalation during construction arising from delays. But cost escalation can also arise without delays – due to real costs increases in materials and labor above the rate of inflation. Adverse exchange rate movements can also cause cost increases, just as favorable ones can cause decreases. Jim Harding, a former utility executive and consultant on economic issues estimates that a range of cost escalation assumptions from zero to 14 percent per year and overnight costs leads to a cost range of electricity of 10.7 to 23 cents per kWh.[44]

F. Estimating total busbar costs of electricity from new nuclear power plants

The total busbar costs of nuclear power should include:

- Capital costs per kWh
- Non-fuel Operating and Maintenance (O&M) costs
- Fuel costs
- Decommissioning costs
- Waste management and disposal costs, including spent fuel as well as other wastes.

At present, non-fuel O&M and fuel costs combined average about under 1.88 cents per kWh in the United States (1.6 euro-cents, rounded). However, these do not reflect higher uranium prices, higher prices for enrichment services that may result from new plants being built, the costs of disposal of depleted uranium, for which there is as yet no suitable disposal path, and potentially higher security costs.

In addition, the problem of spent fuel disposal has not been addressed. If we take the U.S. direct disposal charges currently paid by nuclear electricity consumers, this yields a rather modest cost of 0.1 cent per kWh fixed by the U.S. government in the Nuclear Waste Policy Act. But now the Yucca Mountain program is essentially on its last legs. Since there is no operating repository for spent fuel or high-level waste, there is no really good guide for estimating the costs of a satisfactory repository that will meet the licensing test of reasonable assurance of safe disposal with strict environmental and health standards. It is likely that the 0.1 cent per kWh hour fee will turn out to be quite inadequate. Further, if reprocessing becomes part of the waste management policy, the costs would likely increase to 2 cents per kWh,[45] possibly more. Decommissioning costs are likely to be much smaller than this on a per kWh basis

44 Harding 2008, slide 6.

45 This is the estimated added cost of electricity from mixed oxide fuel made with reprocessed fuel in France. See Arjun Makhijani, *Plutonium End Game*, Institute for Energy and Environmental Research, January 2001

In sum, the costs, other than capital costs, per kWh may be in the 2 cents to 5 cents per kWh (rounded) range, possibly more.[46] For the purposes of this study, we have assumed a range of 1.6 to 2.4 euro-cents, corresponding to recent U.S. costs at the lower end and 50 percent higher than present U.S. costs at the higher end representing the potential for higher waste and fuel costs and other O&M costs.

Overall, a range of 9 or 10 U.S. cents per kWh at the optimistic low end to 20 U.S. cents or more per kWh at the high end represents the range of nuclear electricity costs from new plants about as well as might be anticipated at present. The high end represents a high overnight costs and a high risk premium to represent a variety of cost increases of the sort that have been experienced in the past. The uncertainty in costs of mature renewable energy technologies, notably wind-generated electricity, is far lower. In the case of concentrating solar power and solar PV, the costs are coming down as the technologies mature. Among major electricity generation technologies, solar electricity generation technologies are the only ones where the costs have declined in the past few years.

G. Combining uncertainties

We adopt an approach of using a range of construction costs that reflect present day estimates in the U.S. and Europe of 3,500 to 6,600 euros per kW ($4,100 to $7,700 per kW). The lower end of the range is lower than the detailed Florida Power and Light estimate and is very optimistic; the higher end of the range is about equal to the high estimate made by FPL.

To reflect all the other risk factors, such as long lead times, higher cost of capital due to risk of default (assuming no government backing or loan guarantees, much higher costs of spent fuel disposal at some later, undetermined time, lower electricity growth leading to lower sales or even cancellation of some reactors, we have used a risk premium of 5% over short lead time projects, such as wind or combined cycle natural gas plants. For the latter, we use a range of fuel costs to reflect uncertainty (see below). We note that the high end of the range used for these comparisons does not reflect the full range of risks faced by nuclear plants; a five percent risk premium is too low to do so. A much higher risk premium, such as 8 or 10 percent, is needed to do so.

46 The Joint Keystone Fact Finding which included both nuclear industry and nuclear skeptic experts estimated the range of fuel and non-fuel O&M costs as being much higher: 3.7 cents to 4.9 cents (U.S.) per kWh or 3.2 to 4.2 euro-cents per kWh at 1.17 dollar = 1 euro. Nuclear Power Joint Fact-Finding, The Keystone Center, June 2007, p. 11.

2.2.4 The comparative economics of reducing CO_2 emissions [47]

Much of the debate on reducing and eventually eliminating fossil fuels from the electricity sector has centered on comparing renewable energy systems like wind and solar to nuclear power plants. This is an important exercise. However, a comparison that is restricted to zero- CO_2 electricity sources[48] is far too narrow. The main issue is what will replace coal fired power plants, which account for about 55 percent of Spain's electricity sector emissions.

Consider then the following investment question: how does an investment in nuclear energy compare with an investment in natural gas or wind in reducing CO_2 emissions. In other words, for a given expenditure of money, can more CO_2 be reduced, for instance by investing in combined cycle power plants or wind than by investing in nuclear. The question is evident in the case of wind – it is a straight comparison between two sources of electricity that have no direct CO_2 emissions at the power plant. But combined cycle natural gas power plants do have CO_2 emissions. Yet, it may be that it CO_2 emissions could be reduced more cost effectively by replacing coal-fired power plants with natural gas-fired power plants. Ultimately the gas-fired generation might have to be replaced by zero- CO_2 sources, but the use of natural gas in a transitional role might allow new options to be developed and the cost of existing zero- CO_2 renewable sources to be reduced. Wind generated electricity is equally or more advantageous than natural gas in many cases, depending on the circumstances, the price of gas, the specific wind site and whether storage is involved or not.

We consider the following parameters (costs are in euros and euro-cents unless otherwise mentioned):

- Variable costs of coal-fired generation: 2.4 euro-cents, including fuel and non-fuel costs. [49]
- Emission factors: coal = 950 grams of CO_2 per kWh, combined cycle: 380 grams per kWh, nuclear = zero, wind = zero. [50]
- Fuel cost of natural gas combined cycle power plants: 2.25 euro-cents per kWh, which is the current cost in Spain. Additional non-fuel operating costs of 0.75 euro-cents per kWh are assumed for a total of 3.0 euro cents per kWh in fuel and non-fuel operating and maintenance costs. We also use a high case for natural gas fuel cost assuming a 50 percent increase in the cost of gas to illustrate the effect of a potential rise in gas prices. We stress that his is not an estimate that natural gas prices will increase in a sustained way. The high gas price case is used just as an illustration of a contingency, which shows the relative CO_2 reduction cost in case natural gas prices rise.
- Fuel and operating costs for nuclear = 1.6 euro-cents per kWh in the low nuclear cost case and 2.4 euro-cents per kWh in the high nuclear cost case.
- Capital costs; Nuclear – low: 3,500 case and high: 6,600 euros per kW installed as noted above, 40 year operating life, 90 percent capacity factor.

47 All economic calculations in this paper are on an unsubsidized basis. No government loan guarantees, tax credits, etc. are considered for any electricity source. This enables direct and valid comparisons to be made between different sources of electricity. We do not address the problem of government-subsidized insurance and government mandated limits on liability far below potential accident damages in this paper.

48 Direct emissions only.

49 This is based on July 2008 average U.S. costs converted to euros at 1.17 dollars per euro, which was the issue rate of the euro and corresponds roughly to the purchasing power parity exchange rate. The exact value is not essential as it is used only to estimate the cost differential for replacing a fully depreciated coal-fired power plant with a new power plant. This enables the cost per metric ton of CO_2 to be established for various power plants. Note that all U.S. dollar data are converted to euros at the rate of 1.17 dollars per euro.

50 Based on 1.3 MJ natural gas to heat compressed air for a 90 percent load factor. See below.

- Capital costs natural gas combined cycle = 1,000 euros per kW (rounded). Capacity factor = 90 percent. Based on U.S. costs of about $1,150 per kW. [51]
- Capital costs: onshore wind: low case = 1,500 euros per kW (based on $1,800 per kW) and capacity factor = 35%.; high case: 1900 euros per kW (based on $2,200 per kW) and capacity factor = 25%.
- Interest and depreciation: 8% for wind and combined cycle and 13% for nuclear, reflecting a modest risk premium of 5% (compared to potential high-yield bond ("junk bond") premium that could be much higher, given the various risks involved.

As noted at the outset, these are simplified calculations intended only to compare the approximate cost of CO_2 reductions in the case of replacing existing depreciated coal-fired power plants by new power plants of three types – combined cycle natural gas, nuclear, or wind. If a sensitivity analysis is done, the above parameters yield the values shown in Table 1. Note that while the capital costs for combined cycle and wind are realistic figures, the range for nuclear is very large due to uncertainties and the wide range of experience with nuclear. The low end of the cost range may be unrealistically low to represent the cost of a completed plant.[52] It has been used here as a lower bound to compare whether there is any case for using nuclear to reduce CO_2 emissions compared to natural gas combined cycle power plants. As it turns out, there is not.

Comparing the low natural gas cost case to the low nuclear cost case, we can see that the nuclear plant has a 80 percent greater cost for CO_2 reduction. The high nuclear case is nearly four times the CO_2 reduction cost compared to the low nuclear case. The result is the same when the low nuclear cost case is compared to the low wind cost case. At the high end of nuclear costs, nuclear is also more expensive than the high end of wind energy costs. There is only a marginal advantage for nuclear when the high wind cost case is compared to the low nuclear cost case. This is in my view the result of using a low end value that, at least in the United States, appears unrealistically low. It should also be noted that a proper comparison for policy choices should compare the high cost with the high cost cases and the low cost with the low cost cases.

It is useful to make a "best estimate" or central estimate comparison of these various values. It is also useful to add a storage element to wind to check how that changes the cost relative to nuclear. We chose a natural gas cost of 3.0 euro-cents per kWh for combined cycle power plants, considerably in excess of the present price, but well within the range of spot prices in the last few years. We use a capital cost of nuclear of 5,000 euros per kW and of 1,700 euros per kW for wind; these are approximately the averages of the ranges used in Table 1. A 30 percent capacity factor is used for wind, which is in between the low and high cases.

In order to make the wind-nuclear comparison in a situation of advanced penetration of renewables, we added a compressed energy storage (CAES) component so that wind would be dispatchable rather than intermittent. The estimates of CAES cost are drawn from a detailed assessment done for a Texas wind farm by Ridge Energy Storage & Grid Services.[53] Two large-scale compressed air energy storage systems have been operating in conjunction with coal-fired power plants in Huntdorf, Germany (290 MW) and McIntosh, Alabama (110 MW). The latter has been operating since 1991. Hence ample operational and cost data are available for CAES at

51 *CONE Combined Cycle Revenue Requirements Update PJM Interconnection, LLC. Cost of New Entry Combined Cycle Power Plant Updated Revenue Requirements*, for PJM Interconnection, LLC, August 26, 2008. An escalation corresponding to an inflation rate of 2.5 percent for three years has been taken into account to make the constant 2008 dollar estimates comparable to the FPL nuclear cost estimates. AN average of three values of capital cost cited in this report has been used. Converted to euros at 1.17 dollars = 1 euro.

52 This is the view of Peter Bradford, Former Commissioner of the U.S. Nuclear Regulatory Commission. Peter Bradford, personal communication, 8 May 2009.

53 Ridge Energy Storage & Grid Services, *The Economic Impact of CAES on Wind in TX, OK, and NM, Final Report*, June 27, 2005, p. 82. Hereafeter Ridge Energy 2005.

operational scales for central station generation. The baseload wind concept using CAES, including fuel consumption, is described by the National Renewable Energy Laboratory in a 2007 paper with estimates of fuel use at various capacity factors.[54]

The results of the comparison are shown in Table 2. This shows that the central estimate of nuclear costs in reducing CO_2 is about double that of combined cycle or wind power plants. Even when compressed air energy storage is added at an added cost of just over 3 U.S. cents per kWh (2.6 euro-cents per kWh), dispatchable wind-generated electricity is still somewhat lower in cost than nuclear. The costs of capital and operating costs (modest natural gas costs) are derived from the Ridge Energy study. The capital costs of CAES have been adjusted upward by 50 percent to account for cost escalation between the time of publication of the study (2005) and 2008. Capital cost represents about two-thirds of the total annual cost of CAES in 2005 and about three-fourths of the cost in the 2008 calculation shown in Table 2.

2.2.5 Conclusions

This analysis shows that the common assumption in many circles that nuclear is essential for reducing CO_2 emissions is incorrect. On the contrary, emissions can be more effectively reduced at much lower risk if existing coal-fired power plants are replaced by wind and combined cycle power plants. In the long run, natural gas can be replaced by biogas derived from biomass for instance to eliminate the CO_2 emissions associated with it and also to eliminate the risk of natural gas price increases over the long-term. Even when compressed air energy storage is added to wind to make it dispatchable, the costs of CO_2 reduction are slightly higher for the central estimate of nuclear than for wind with storage.

It does not appear desirable to take the risks associated with nuclear power both in regard to waste and money in order to reduce CO_2 emissions. Moreover, given that the lead time for building nuclear power plants is 8 to 10 years (perhaps more in case of long delays), CO_2 reductions can be carried out much more rapidly if renewable energy is deployed, since renewable projects typically take two to three years or less. Therefore, there could be a substantial CO_2 cost penalty associated with using nuclear power due to its long lead time. The nuclear industry will also take time to ramp up. In the United States, it is anticipated that less than ten plants and possibly less than half that will be built in the next ten years. The amount of equivalent renewable capacity, in terms of generation and hence CO_2 reductions, that can be brought on line in that time could be many times that. When combined with large efficiency investments and investments in storage, the overall share of the cost of electricity in the Gross Domestic Product can be maintained even if renewable electricity remains somewhat more expensive than conventional fossil fuel generation (in the absence of CO_2 charges).

Nuclear power is a distraction from the real task at hand – transitioning to an efficient, smart-grid electricity system based entirely on renewables. John Wellinghof, the Chairman of the U.S. Federal Energy Regulatory Commission, has recently noted that there may be no need for new nuclear or coal plants ever.[55] My research indicates that he is right. Policies in regard to existing nuclear plants can safely be based on the assumption that we will be able to phase them out and that we will not need new nuclear power plants to address climate change concerns.

54 Derived from National Renewable Energy Laboratory, *Creating Baseload Wind Power Systems Using Advanced Compressed Air Energy Storage Concepts*, 2007, on the Internet at http://www.nrel.gov/docs/fy07osti/40674.pdf. Hereafter NREL 2007.

55 Noelle Straub and Peter Behr, "Energy Chief Says New Coal, Nuclear Plants May Be Unnecessary, *New York Times*, April 22, 2009, on the Internet at http://www.nytimes.com/gwire/2009/04/22/22greenwire-no-need-to-build-new-us-coal-or-nuclear-plants-10630.html

Table 1: Comparison of CO2 reduction costs: combined cycle, nuclear wind

Power System	Capital Cost euros/kW	Interest + Depreciation euro-¢/kWhe	Fuel and non-fuel O&M cost euro-¢/kWhe	Total cost euro-¢/kWhe	Coal, variable costs only	Add cost over coal euro-¢/kWhe	CO_2 displaced per kWh, grams	euros per mt CO_2 displaced	Ratio CO_2 reduction cost: low nuclear to alternative	Ratio CO_2 reduction cost: high nuclear to alternative
CC – present gas cost	1000	1.2	3.0	4.2	2.4	1.8	570	31	180%	389%
CC – high gas cost	1000	1.2	4.1	5.3	2.4	2.9	570	51	110%	239%
Wind low case	1500	4.6	0.8	5.4	2.4	3.0	950	31	180%	389%
Wind high case	1900	8.1	0.8	8.9	2.4	6.5	950	69	82%	178%
Nuclear Low	3500	6.2	1.6	7.8	2.4	5.4	950	56	100%	217%
Nuclear High	6600	11.6	2.4	14.0	2.4	11.6	950	122	46%	100%

Table 2: Central estimate values for combined cycle, wind, wind with storage, and nuclear in for CO2 reduction

Power System	Capital Cost euros/kW	Interest + Depreciation euro-¢/kWhe	Fuel Cost euro-¢/kWhe	Non-fuel O&M ¢/kWhe[3]	Total cost euro-¢/kWhe	Coal variable costs only	Add cost over coal euro-¢/kWhe	CO_2 displaced per kWh, grams	euros per mt CO_2 displaced	Ratio CO_2 reduction cost: nuclear to alternative
Combined Cycle	1000	1.2	3.00	0.8	4.9	2.4	2.5	570	45	198%
Wind	1700	6.1	0.0	0.8	6.9	2.4	4.5	950	47	188%
Wind with storage	1700	6.1	2.6 (Note 1)	0.8	9.5	2.4	7.1	850 (Note 2)	83	106%
Nuclear	5000	8.8	1.0	1.0	10.8	2.4	8.4	950	88	100%

Note 1: Fuel, non-fuel, and capital cost for Compressed air energy storage (CAES); see discussion above.
Note 2: About 100 grams of CO2 per kWh would be emitted in using wind with CAES in a baseload mode. See NREL 2007.

2.3 Eight Arguments Against the Use of Nuclear Power [1]

The global nuclear lobby argues that it, alone, among the existing sources of conventional power, does not emit harmful CO2 and therefore can take up the breach and supply an increasing amount of the world's energy and, in the process, help mitigate global warming. Leaving aside the fact that renewable forms of energy – wind, solar, geothermal, hydro, biomass, and ocean waves – might prove a better option, there is little likelihood that nuclear power will provide much assistance in addressing global warming, but a great deal of concern that it might careen the world into a new nuclear arms race.

1. To begin with, there are approximately 440 nuclear power plants online in the world. They generate approximately 6% of the world's energy. The nuclear power plants are old – only a few nuclear power plants have been built since the 1990s – and will soon require replacement. With a minimum price tag of $2 billion each, it would cost upwards of a trillion or more to replace the existing stock. With global population predicted to increase from 6.8 to 8 billion people between now and 2025, this would mean that nuclear power's share of world energy production would be even less than 6%.

   But to have even a marginal impact on climate change, it would be necessary for nuclear power to generate at least 20% of the world's energy. This would require replacing all 440, or so, existing power plants and constructing an additional 1,500 plants for a total of nearly 2,000 nuclear power plants – at a cost of nearly $9 trillion. This is exactly what the International Energy Agency is proposing. To accomplish this Herculean task, we'd have to put under construction three nuclear power plants every 30 days for the next 60 years – a feat that even the power and utility companies around the world believe is a pipe dream.

2. Even if we could build that many nuclear power plants, there is the problem of uranium availability. According to the International Atomic Energy Agency (IAEA) the available uranium resources could fail to meet requirements of even the existing nuclear power plants as early as 2026, in the case of high-demand use and by 2035 in the case of middle-demand use. Of course it is possible that new exploration could lead to the discovery of new deposits, but at what price?

3. There is also the question of disposing of nuclear waste. We are 60 years into the nuclear era and our scientists and engineers still don't know how to safely transport, dispose of, and store nuclear waste. The result is that spent nuclear rods are piling up in nuclear facilities all over the world. In the U.S., the federal government spent more than $8 billion and 20 years erecting what was supposed to be an airtight, underground burial tomb dug deep into Yucca Mountain in Nevada to hold the radioactive material. The vault was designed to be leak-free for 10,000 years. Unfortunately, the Environmental Protection Agency (EPA) already concedes that the underground storage facility will leak.

4. Still more important is the question of water availability. Massive volumes of water are required to cool the reactors in nuclear power plants. France, with its 59 nuclear power plants, produces 78% of the country's energy – consumes 40% of all the country's freshwater each year to cool its nuclear reactors. The heated

1 This chapter is authored by Jeremy Rifkin, President of the Foundation on Economic Trends.

water then flows back into the rivers and streams, dehydrating them, resulting in less available water for other human needs. With climate-change induced drought already plaguing many countries, the prospect of finding enough water to both run nuclear reactors and provide for the rest of society's needs becomes increasingly problematic. The U.S. is facing the same problem of water deficits in the southeastern states. With climate change induced droughts already plaguing the region, there is less water available to provide for both costly nuclear reactors and for irrigation and drinking.

5. Moreover, the prospect of building hundreds, even thousands of nuclear power plants in an era of spreading regional conflict seems daft. On the one hand, the U.S., the European Union, and much of the world is frightened over the mere possibility that just one country, Iran, might get its hands on enriched uranium from its program to build nuclear power plants, and use the material to build a nuclear bomb. On the other hand, many of the same governments are anxious to spread nuclear power plants around the world, placing them in every nook and cranny of the planet. This means uranium and spent nuclear waste in transit everywhere and piling up in makeshift facilities, often close to heavily populated urban areas.

6. Security concerns become even more contentious in light of the new generation of French nuclear power plants that are being designed to recycle uranium into plutonium. The thought of plutonium getting into the hands of terrorist groups and rogue countries sends shivers down the spines of security analysts. Nuclear power plants are the ultimate soft target for terrorist attacks. On November 8, 2005, the Australian government arrested 18 Islamic terrorists who were allegedly plotting to blow up Australia's only nuclear power plant. Had they succeeded, Australia would have experienced its own devastating version of the catastrophic 9-11 attack that crippled New York City. We should all be very worried. A Nuclear Regulatory Commission study in the U.S. found that over half of America's nuclear power plants, in the sample survey, failed to prevent a simulated attack on their facilities

7. Nuclear power represents the kind of centralized power generation used in the twentieth century. In the new era of distributed grid IT and renewable energies, businesses and homeowners will increasingly produce their own power onsite - collecting solar, wind, hydro, geothermal, garbage, agricultural and forestry waste, and tidal - store the power in the form of hydrogen, and share surpluses with millions of others across smart inter-grids, just like they now produce their own information and share it across the internet. The potential of distributed, renewable power exceeds, by a magnitude, the potential power that can be generated by nuclear power plants.

8. Finally, while nuclear energy is a far more expensive source of power generation than renewable energies, it produces only a handful of jobs, and has virtually no multiplier effect on the economy. The shift to distributed, renewable energies, by contrast, will create hundreds of thousands of jobs in Spain, installing renewable energy technologies, converting existing buildings to collect energy onsite, establishing hydrogen storage infrastructure, reconfiguring the Spanish power grid, and retooling the transport industry with electric plug-in and hydrogen powered fuel vehicles.

3 Scenarios for a model based on 100% renewable energy by 2050 [1]

The last chapter supported a new, forward-looking energy model aimed at solving current problems. The second chapter listed the reasons which explain why nuclear energy is not the answer to problems which we face today. The authors of this report are all in agreement that renewable energy sources should be the core component of a long-term energy model for Spain.

3.1 Introduction

This chapter provides several scenarios showing a generation mix based on renewable energy to satisfy total electricity demand for the peninsular Spanish market by 2050 and analyzes the feasibility of eliminating nuclear and fossil fuel sources during the intervening period.

The issue is not whether it is possible or not to satisfy the demand for electricity exclusively through renewable energy sources. In our opinion, this is not questioned, given existing potential, sector analyses and instruments available to ensure the viability of such a generation mix. The question rather addresses specific areas within this sector, as well as the political and regulatory considerations required to promote the development of these energy sources within the short span of time available so as to shift the future development of our energy sector towards a model based on sustainability.

If we consider uncertainties governing forecasts regarding the demand for electricity in 2050, which will depend on factors such as population trends, degree of implementation of energy-efficiency measures, and the level of electric power required for energy-dependent sectors such as construction and transportation, we have decided on three scenarios defining the availability of sustainable power demand models. These three models cover a range (418 TWh/yr – 152 TWh/yr), which include the probable demand for electric power through to 2050.

There is significant potential for the use of renewable energy in Spain, given the wide scope for flexibility in the national electric grid provided not only by those sources, but also from developments in the grid itself, the operational use of electricity, and changes in other energy sectors. This flexibility also relies on a number of factors (such as increased generation and demand, technological diversity, territorial distribution, rapid regulatory response in generation, storage capacity, intelligent networks, demand management, electric-powered vehicles, etc.), so that there are multiple, varying scenarios for power generation exclusively dependent on renewable sources to satisfy 100% of power requirements. The final configuration resulting from the mix of these renewable sources will depend, to a large extent, on the implementation of policies aimed at supporting their introduction to the market as well as on barriers potentially resulting from inadequate regulation and insufficient support.

Within the wide range of renewable options available to satisfy the demand for electric power we have decided to focus on those based on technological diversity and assumed, within a conservative approach, a limited level of development of demand-management alternatives.

Thus, for the three power demand scenarios we have selected (418 TWh/yr, 280 TWh/yr and 152 TWh/yr) we provide a generation mix relying on installed capacities of, respectively, 147 GW, 104 GW and 68 GW. If we

1 Chapter drafted by Xavier García Casals, PhD Aeronautical Engineer and Consultant.

assume an hourly distribution of demand throughout the year similar to that of 2003, the result would be solar multiplier factor[2] (SM) generation values of 2,2, 2,3 and 2,8. For purposes of comparison the value of the parameter equivalent[3] to the solar multiplier factor in the peninsular power system for 2008 was 2,1, so that the structure of a renewables-based generation system should not differ excessively, as far as SM factor requirements, from current levels.

The basic component for a renewable source power system is, conceptually, its flexibility[4] (IEA, 2008). There are numerous flexible elements present in renewable energy sources, as there are in the evolution of electric power, to bring about such sustainable power systems.

Flexibility is a component in generation, including rapid response in most renewable technologies, significant storage capacity in a number of them (such as that of thermo-solar plants) and, particularly, availability of operating power provided by technologies such as regulated hydroelectricity, hydroelectric pumping and, especially, hybrid power through biomass in thermo-solar plants. A few of these flexible components, now available in the system, would make a renewables-based generation systems viable.[5]

Demand, in turn, provides even more promise in the use of a larger number of flexible mechanisms, most of them involving an intelligent transportation and distribution network. Implementing these possibilities means reducing the need for installed capacity in generation (and therefore its cost) as compared with reaching the necessary levels of flexibility only in generation. This would include demand management components, an intelligent management of distributed power (including inter-connection between vehicles and the grid – V2G), and intelligent management of distributed power storage in practically all energy sectors (construction, transportation and industry).

Renewable-based generation mix models mentioned in this chapter may be seen as a conservative approximation in that they presuppose a limited penetration of demand management components and imply a minimum diversity in the generation mix, which could lead to renewables-based power system configurations incorporating a lower need for installed capacity.

The 100% Renewables analysis mentions generation mix models based on renewable energy sources obtained through economic optimization. These models show how it is possible to satisfy the same level of demand by means of lower total installed capacity in exchange for giving up technological diversity. However, given the diversity of renewable sources in the Spanish market, it is our opinion that it would prove more appropriate to rely on a generation mix involving a higher level of technological diversity which, besides providing higher levels of guarantee in supply, would lead to significant changes in economic activity elsewhere on the globe, providing market opportunities for Spanish business and industry.

Regarding possible scheduling of nuclear and fossil-based power plant shutdowns, the scenarios included in this paper indicate that it is possible to do away completely with nuclear sources by 2016 within the scenario

2 The generation system's solar multiplier factor is defined as the result of dividing installed capacity by maximum annual demand, and is an adequate means to assess the coverage provided by the grid in covering gaps in generation capacity (which in renewables-based systems is not only the result of unavailability of power output from generation plants, but is basically the result of the fact that nominal installed capacity is significantly different from real power available at any given time as a factor of seasonal changes in each energy source) and the possibility of simultaneously storing power while satisfying demand at times when generation is not possible.

3 Equivalent as a concept, since it is the result of dividing installed capacity by peak demand. However, the term 'Solar' might lead to confusion since the current power generation system is not exclusively based on renewable energy.

4 We should mention that nuclear plants are opposed to the flexibility required to operate an intelligent power system which includes a high percentage of renewable sources. In this sense highly inflexible technologies, such as is the case of nuclear, hinder the development of renewables-based generation systems.

5 Such as the approximation applied in Greenpeace's 100% Renewables analysis.

involving average demand, given the possibility of installed capacity levels of renewable energy sources without increasing the use of fossil fuel. However, the complete elimination of fossil fuels within the power generation system strongly depends on flexible mechanisms in generation introduced as part of the process for the development of a generation mix based on renewable energy sources for 2050. In fact, the average demand case analyzed in the paper shows maximum levels of demand at around the year 2030, where demand levels are forecast to be significantly higher than in 2050. On those dates when the highest levels of demand are forecast, the renewables-based generation mix required to satisfy the demand forecasted for 2050 should be fully implemented. Thus, if the generation mix does not include excess capacity, fossil fuels might be required to cover the deficit in generation for the middle of the period under consideration. If excess capacity is not built into the renewables system it would be necessary to wait until 2043 in order to do completely away with fossil fuel, although their contribution would reach significantly lower levels than existing by 2016. It would, however, be possible to do fully away with fossil fuel in power generation by 2025 through the introduction of higher flexibility in the renewables mix, basically by increasing the percentage of thermo-solar plants featuring thermo-solar hybridization capacity from the 22.6% initially planned for 2050 to 51.6%. This strategy would require a relatively small increase in the volume of investment in generation and a higher consumption of biomass over the middle years considered in the scenario, which would also provide additional power generation flexibility in order to respond to unforeseen contingencies or deviations from scenario parameters.

We may therefore conclude that resources available are more than sufficient if we decide to devote our efforts towards a new configuration of our electric power generation model towards a system exclusively based on renewable sources. To this end, there are a number of extremely varying alternatives, both in generation and in demand, which, were they to be implemented in a timely fashion, would allow us to both complete a rapid transition and to define the cost components of the resulting power system. The only significant barrier is the capability of implementing, and maintaining, a favourable, stable framework in order to promote a rapid development of the types of technology required.

3.2 Scenarios for power demand

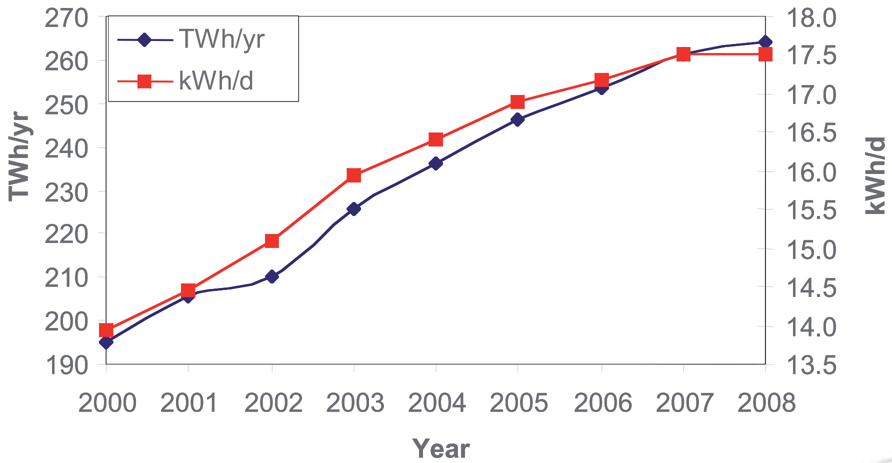
Spain's economic and energy framework is currently undergoing structural changes, which result in major uncertainties regarding future developments in power demand, particularly when forecasting to remote future markets such as that for the year 2050. Some of the leading factors which will have a bearing on demand (both in terms of total figures as well as concerning seasonal and hourly distribution patterns), where there is currently major uncertainty, are as follows:

- Future population development patterns
- Electric power availability in transportation (shift in pattern and electric vehicles)
- Electricity in the construction sector
- Level of new measures leading to energy efficiency
- Pattern of economic growth and energy intensity
- Number of measures necessary to incorporate new demand management decisions

In spite of all the above observations, we have decided to pursue three power demand scenarios (high. medium and low) to include the highest number of possible solutions to be expected concerning electric power requirements for the year 2050. These three demand scenarios will be used throughout the paper to define the structure of power generation systems based on renewable energy required to satisfy projected demand.

Past demand patterns in Spain (peninsular market) are shown in Chart 3.1, which indicates total and per capita demand between 2000 and 2008.

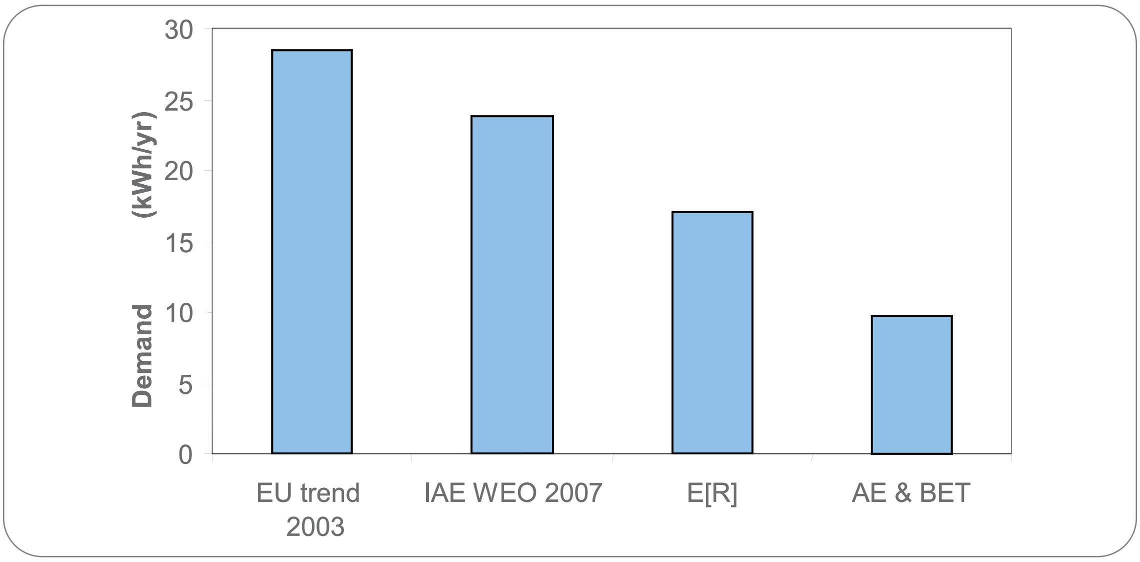
Chart 3.1: Electric power demand in Bus bars for Spanish peninsular grid



(data provided by INE and REE)

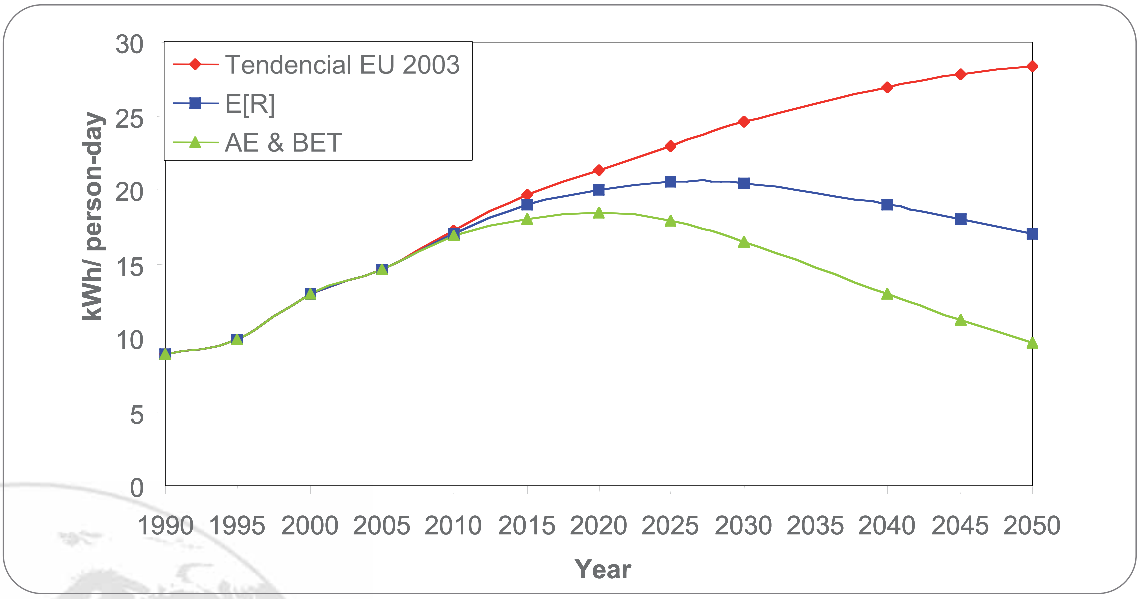
Chart 3.2 shows forecast per capita power demand for the year 2050 according to the different scenarios, where it is possible to observe the resulting major changes in projected values. Chart 3.3 shows forecasts concerning demand performance to 2050 in three of these scenarios.

Chart 3.2: Projected power demand values, per capita, for 2050.



EU trends are provided in accordance to EU 2003 levels through to 2030, extrapolated to 2050. E{R] shows the scenario obtained from Greenpeace figures, while AE & BET shows a high-efficiency, low-power scenario for the transport sector defined in accordance to transportation indicators as defined within this analysis.

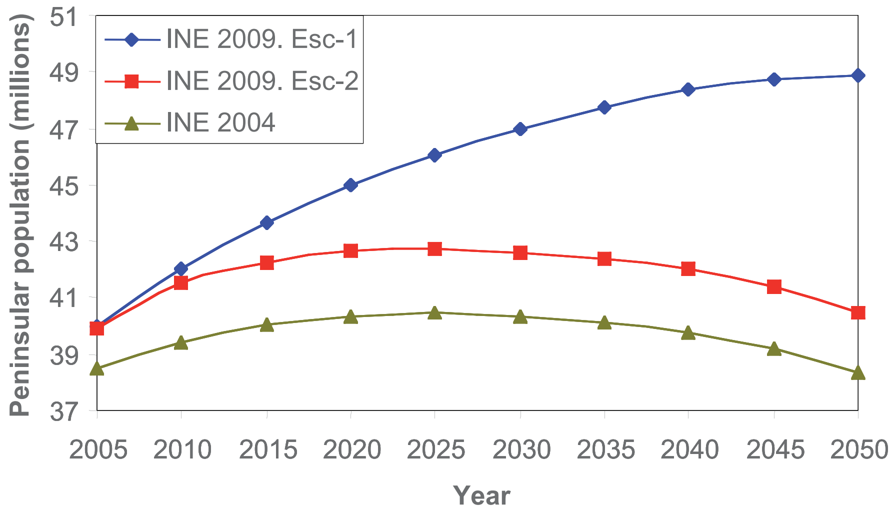
Chart 3.3: Different scenarios for growth of per capita demand through to 2050.



The EU 2003 trend reaches 2030, and was extrapolated to 2050, E[R] is similar to the Greenpeace Energy [r]evolution analysis, and AE & BET shows a high-efficiency, low electrification model fro transportation as shown in this analysis.

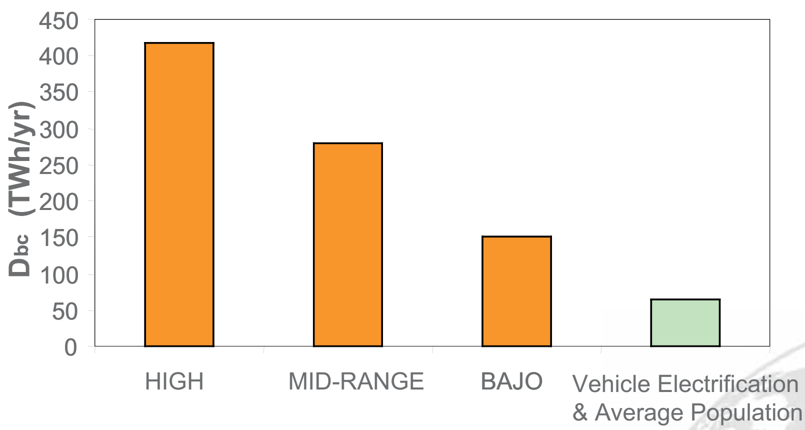
Besides a major dissemination of data in per capita demand scenarios for 2050, population models for the same time series also indicate high levels of variability, as may be seen in Chart 3.4, basically responding to immigration data.

Chart 3.4: Varying scenarios for population shifts in Spain (peninsula).



Within the above framework we have chosen, for the purpose of this paper, three different demand scenarios to establish the bracket including the majority of probable options. Chart 3.5 shows these three demand scenarios alongside an assessment of power demand according to total electrification of the vehicle pool for 2050 within an average population forecast, which represents one of the leading uncertainties affecting demand as mentioned above.

Chart 3.5: Three power demand scenarios forecast for the peninsular market, 2050.



Also shows power demand in a scenario including full vehicle pool electrification in an average-population growth scenario.

We now turn to the potential repercussions of each of these power demand scenarios in order to understand the implications of each of the possible results to be expected:

HIGH-demand scenario:

This case could show a BAU scenario such as that of reference included in the IEA's WEO 2007 report (final per capita demand = 24.2 kWh/person-day) within a medium level of population in peninsular Spain (44.67 million population).

MID-RANGE demand scenario:

This could be a scenario which includes medium-to-high implementation of efficiency measures as compared to the IEA's WEO 2007 BAU study (44% savings excluding transportation power demand coverage), electrification of the transportation sector[6] of around 27% and an average population of some 44.67 million.

This scenario involves the same level of efficiency measures in terms of the WEO's 2007 BAU results excluding transportation (a savings of 44%) as the Greenpeace Energy [R]evolution text (Greenpeace, 2008), but includes lower electrification of the transportation sector.[7]

This mid-range scenario (280 TWh/yr) coincides with the demand model used in the Greenpeace Renewables 2050 and 100% Renewables reports.

LOW demand scenario:

This scenario could respond to a situation featuring implementation of high efficiency measures in comparison with the IEA's 2007 BAU model (savings of 60% in total power demand) together with low electrification of the transportation sector and low population growth (40.49 million), thus indicating a lower demand, in accordance with lower values to be expected for power demand in 2050.

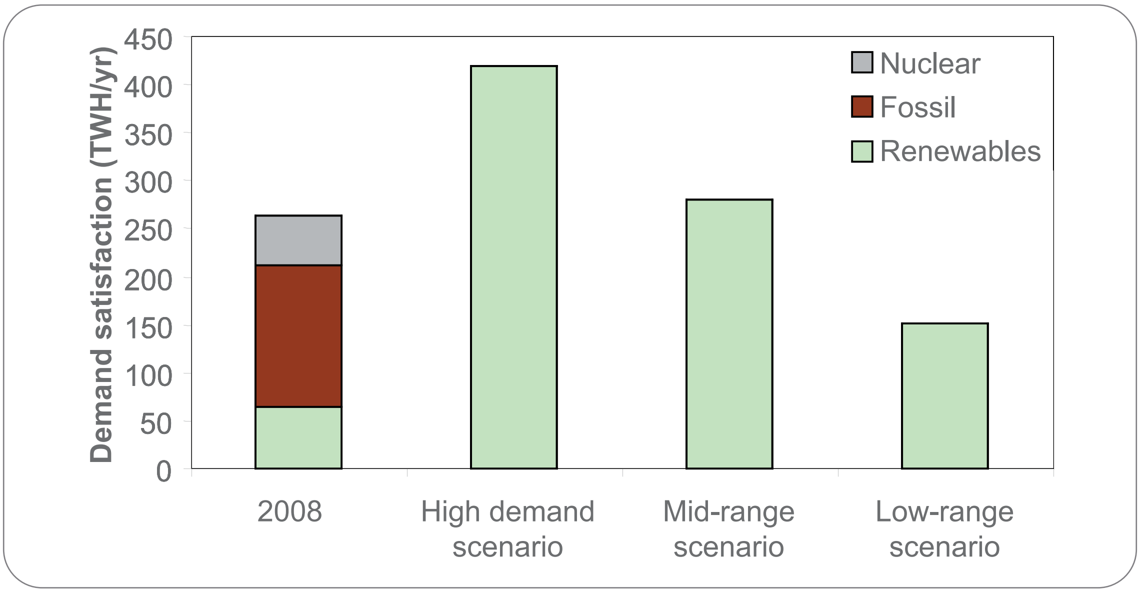
In order to compare these figures with existing real-market power demand levels, Chart 3.6 shows these scenarios together with peninsular power demand for 2008 and supply provided through the various energy sources (results processed and provided by REE, 2008, and CNE, 2009). Data indicate that for a wide range of scenarios included between the mid- and low ranges, input obtained from the entire nuclear power generation available would cover demand to a negligible, or marginal, level, and would thus be subject to elimination independently of the speed of implementation of renewable energy. In fact, particularly in low-demand scenarios, the presence of nuclear power - given the very low level of flexibility – would introduce significant restrictions to the economic feasibility of implementation of renewable sources. For example, we could only mention that during the early morning of November 2, 2008, REE had to lower wind production output given the lack of demand during those off-peak hours, thus reducing wind generation by 2.8GW (36.3% of the level of installed nuclear generation capacity) as a result of the inflexible nature of the nuclear component, which accounts for most of the power generated at that time of the day, in order to continue generating wind-based energy. This situation will become more frequent as renewable sources continue to grow as element in generation, will bring about significant losses in compensating these new technologies, thereby partly neutralizing the existing support mechanism implemented with the purpose of promoting their use. It is, therefore, recommendable to do away with the nuclear generation sector as rapidly as possible.

6 We should note that this level of electrification includes not only electric-powered vehicles, but also modal changes. For reference purposes the IEA's WEO 2007 report is based on a hypothesis of 4.3% electrification in transportation.

7 Electrification of transportation in this scenario, based on its structural components, including demand, shown in the Energy [r]evolution model, would be 27.3%, versus 35% as shown in Energy [r]evolution. However, this comparison should be maintained for qualitative purposes given that lower levels of electrification imply changes to the demand structure in transportation.

It is also worthy of note to remark that shutting down the nuclear generation component while promoting the use of renewable sources, together with measures tending towards improved demand efficiency and management, should not necessarily entail an increase in the consumption of fossil fuels to reach demand levels, even if the new pool of renewable fuel sources were unable to satisfy demand at peak hours or at those times currently covered by nuclear generation. Implementing higher levels of renewable sources would only result in a displacement of fossil fuel as a source (due to higher flexibility in combined-cycle plants) towards those times of the day when renewable sources face decreased capacity in satisfying existing demand.[8] What is more, given the wide range of options available in terms of demand management (intelligent networks) and energy efficiency, implementing renewable sources could even take place while reducing fossil fuel consumption.

Chart 3.6: Comparison of three power demand scenarios showing power consumption and the structure of supply for the peninsular power system, 2008.



Finally, we should also mention that there is a specific effect which electrification of the vehicle pool may have on renewable-source generation systems.

If we consider a mid-range population scenario for 2050 (44.67 million) with vehicle ownership rates 20% below current levels, in order to account for higher efficiency in vehicle use,[9] a vehicle pool with average consumption rates of 0.15 kWh/km using 40 kWh batteries, and availability of charging connections and 10 kW power injection modules feeding from the grid to the vehicle (V2G), this electrification model for the transportation sector would bring about the following results on a generation system based on renewables:

- Increase of 60.3 TWh/yr in final power demand. This demand would account for 16.6% of total demand in the high-level scenario, 24.8% in the mid-range, and 45.6% in the low-range model.
- Availability of operating power in generation, within the V2G model, of between 89 GW and 125 GW in transportation peak and valley hours respectively.

8 In this sense nuclear generation is currently in direct competition with renewable sources, even if they do not overlap during the same demand times.

9 For example, through an increase in infrastructures and policies tending to vehicle-sharing transportation models

- Availability of distributed storage capacity which could be incorporated to demand management programs reaching between 0.5 TWh and 0.36 TWh in transportation valley and peak hours respectively.

Therefore, besides obtaining a significant increase in total power demand (whose importance grows as a function of increased efficiency in the remaining areas in the power system), vehicle electrification through V2G models would bring about two important elements to a generation system based on renewable energy: operating power and storage capacity.

The Greenpeace 100% Renewables study showed that a generation mix based on renewable energy to cover peninsular power requirements makes the availability of operating power (generation + demand) even more critical than access to storage capacity. Indeed, without reaching maximum generation levels, and excluding all potential demand management action, a demand scenario of 280 TWh/yr (mid-range model in this paper) requires no more than storage capacity levels of 1 TWh to match generation to demand, while the requirement for operating power would reach some 20 GW. In other words, power regulation requirements are far higher than energy requirements in a renewables-based generation model. [10]

In this regard, we can draw the conclusion that vehicle electrification, besides allowing us to reach higher efficiency levels in this sub-sector, also has the characteristic in line with the requirements of a generation system based in renewable energies.

3.3 Observations and options towards full supply based on renewables sources to satisfy demand

This section includes a series of results and observations regarding the evaluation of the alternatives towards satisfying power demand through a generation mix based exclusively on renewable energy sources.

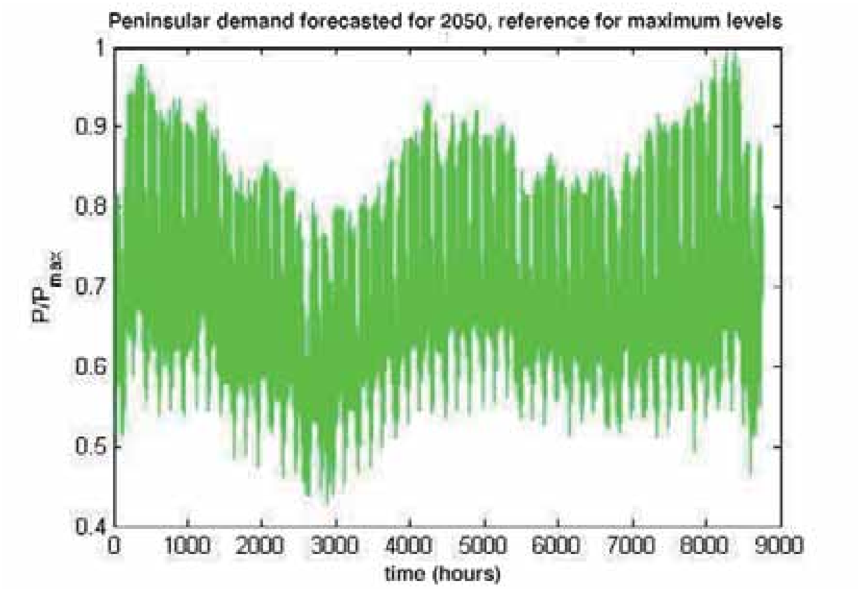
Results included are obtained from the Greenpeace 100% Renewables, which also contains a large amount of additional information regarding both the hypothesis and the calculation methods leading to these results.

In general, it seems important to stress that these scenarios are conservative, in the sense that they assume no action whatsoever in terms of demand management, and set limit to options available in generation mix models based on renewable sources, so that they globally lead to installed power requirements higher than those we would face if we include demand management inputs.

In fact, the hourly distribution of power demand assumed in the 100% Renewables study corresponded to the behaviour of hourly peninsular demand patterns observed in 2003 (Chart 3.7), so that it presupposes a full demand defined as completely “blind” to regulation requirements for the generation pool. The case we submit shows forecast demand levels of 280 TWh/yr for 2050, with peak demand reaching 45.07 GW and minimum demand at 19.36 GW.

10 It appears obvious that demand management policies can lead to significant decreases in the requirement for regulation.

Chart 3.7: Hourly pattern of electric power demand as included in the 100% Renewables study corresponding to hourly peninsular consumption in 2003



One of the primary relevant results obtained in the 100% Renewables study concerning the possibility of satisfying demand through a renewables-based generation system is the variety of the significant effects of regulating generation capacity resulting from territorial distribution and technological diversity. Indeed, the classical cliché which states that renewable energy sources are so discontinuous in terms of generation that they cannot match demand requirements unless by means of an outrageous storage capacity may be true for an isolated, low-power system based on wind or PV technology, but is absolutely untrue for a system scaled to the peninsular power grid featuring a sufficiently high level of diversification of the technologies involved.

This being said, we will now submit a number of the results of implementing two mix models, in order to discuss the peculiarities of renewables-based sources, as included in the 100% Renewables study, in which both models reach 100% demand satisfaction.

The first is mix-27, whose installed power distribution is shown in Chart 3.8, and which does not require many of the mechanisms provided by renewable energy sources in matching demand. Indeed, it does not even incorporate the possibilities which result from regulation-capable hydro plants currently in use within the existing generation system. It also does not include the major levels of operating power generated by hybridization through biomass provided by thermo-solar plants, nor the thermal storage capacity of thermo-solar plants (which, for the installed capacity of this technology, reaches 74.3% of average daily demand). The regulation components available in this mix are thus limited to two of the options available, as follows:

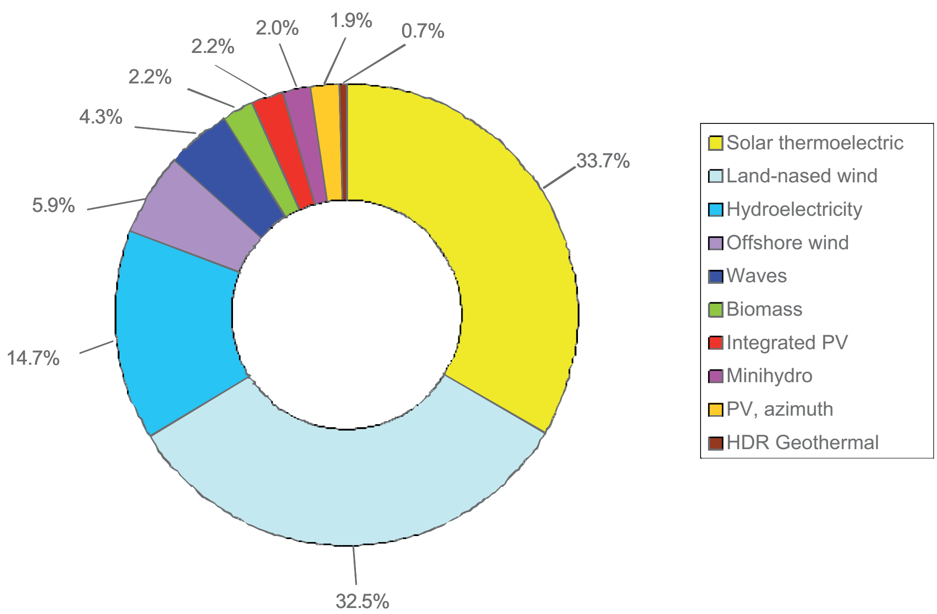
- Excess capacity in the generation pool to be regulated by means of excess generation capacity.
- Storage capacity levels of 1.5TWh, within the range of that currently in operation in hydroelectric pumping in the peninsular system.
- Installed power of 2.5 GW of biomass subject to regulation.

Under these conditions, the level of regulation required to satisfy demand involves dissipation of a large fraction of available generation capacity (in this case 34.4% of energy used to satisfy demand).

Chart 3.9 shows the annual hourly distribution of demand, power delivered, dissipation requirements and unsatisfied demand. The first comment would be that unsatisfied demand is zero throughout the year, that is, power delivered is equal to power demand throughout all hourly segments for the year, with full demand satisfaction through renewable generation. The second observation concerns the significant amount of power dissipated through a large fraction of the year. Finally, Chart 3.10 shows hourly regulation of elements not associated to dissipation of generation capacity in this mix (biomass-based storage and generation capacity).

We may thus conclude that, as a result of the high response speed in most renewables-based generation technologies, it is possible to satisfy demand through relatively low levels of installed power (SM = 2.5 is not excessively higher than the 2.1 included in the peninsular grid in 2008), but this requires a significant level of dissipation of generation capacity, so that it appears likely that other mechanisms involving flexibility within the power system[11] would result in lower energy costs.

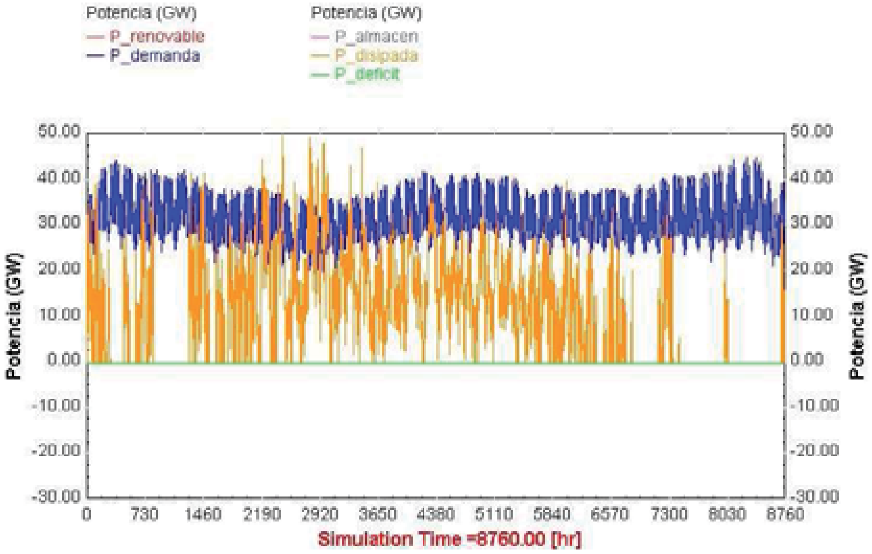
Chart 3.8: Distribution of installed capacity in mix-27. Total installed generation capacity is 113 GW, a solar multiple of SM = 2.5, with storage capacity of 1.5 TWh.



Greenpeace 100% Renewables study.

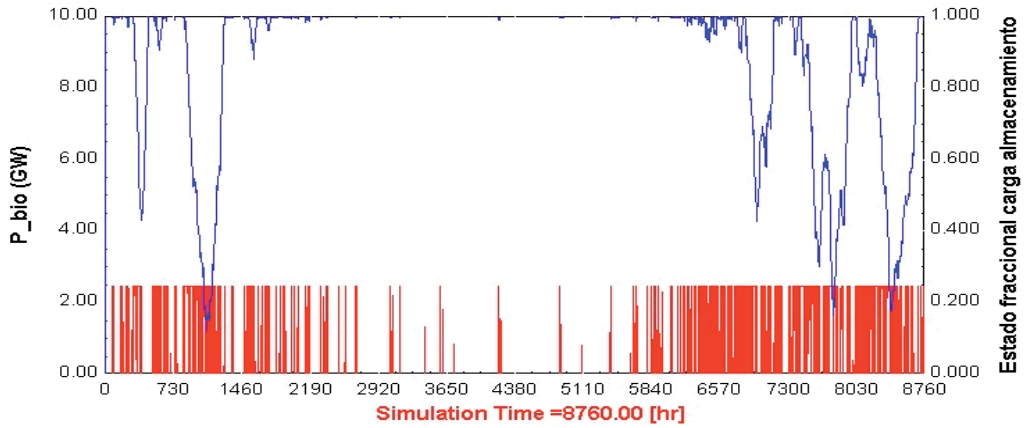
11 These would include integrating the power system with all other energy systems in order to make the best possible use of this "residual electricity" within a more integrated demand management model.

Chart 3.9: Annual hourly demand, power delivered, dissipation requirements and unsatisfied demand in mix-27.



Greenpeace 100% Renewables study.

Chart 3.10: Annual hourly load status in storage capacity of 1.5 TWh and use of biomass with mix-27.



Greenpeace 100% Renewables study. .

The second mix we have selected for comment is mix-32, which is the result of an optimisation process linking increased generation and delivery with the cost structure used in the 100% Renewables study. This mix involves additional mechanisms for higher flexibility in the power sector than those in mix-27 above, and therefore leads to satisfaction of demand through much lower levels of installed capacity (and cost). The specific additional mechanisms leading to higher flexibility included in this model are as follows:

- Optimisation in the operation of regulation-capable hydro plants
- Optimisation of hydro pumping
- Hybridization of thermo-solar plants with biomass

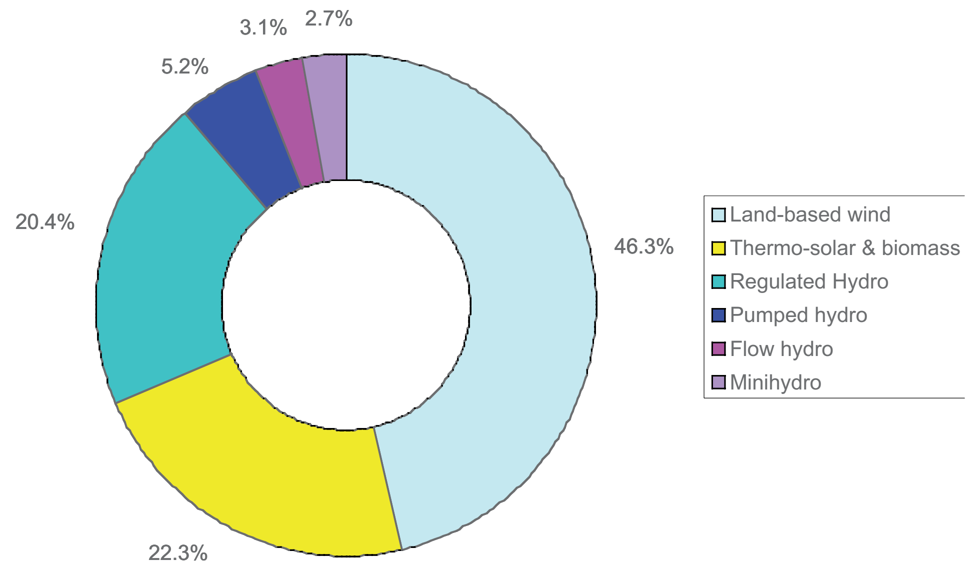
In terms of regulation-capable hydro plants, installed capacity is similar to that of the existing power system, while the capacity of reservoirs is the same as currently available. Hydro pumping levels included in the model (4.2 GW) are slightly higher than those now available.

This generation mix (within an economic optimisation framework) involves hybridization of thermo-solar plants with biomass as an element which improves the level of system flexibility in generation which is both important and limited in terms of cost. This hybridization allows for use of installed capacity in thermo-solar plants for operating power output (in this case reaching 18 GW) with almost no additional investment required as compared to a situation demanding the construction of plants dedicated strictly to biomass. Indeed, in these generation mix models biomass is considered a regulation component, so that if it were decided to incorporate it along with plants exclusively devoted to biomass its low capacity factor would mean that they are not economically interesting for power delivery (or else, that if installed, power output would not be economically acceptable). In fact, concerning dedicated biomass plants the result would be that maintaining continuous power would prove to be excessively costly (and inefficient in energy terms) so as to begin operations, given the short response times required for system regulation purposes. As far as hybridization with biomass in thermo-solar plants, both problems would be resolved, so that biomass would become an important component in regulation, while retaining limited levels of biomass consumption (regulation in this case is more important in terms of power, rather than of energy).

Chart 3.11 shows the distribution of installed power within this mix model which, base don 81.2 GW will provide an SM value of 1.8 (significantly lower than the 2.1 figure obtained in the peninsular power system for 2008). Chart 3.12 shows the distribution of delivery of that mix for full satisfaction of power demand.

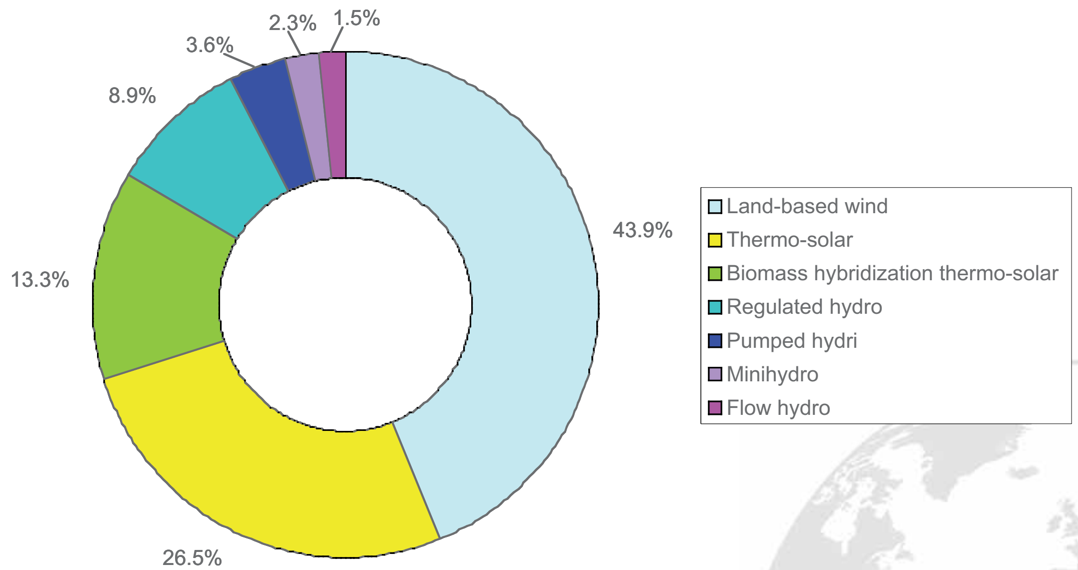
As seen in these figures, technical-economic optimisation leads to a generation mix based on renewable energy sources with an installed power capacity which significantly lower and a cost of power output also significantly lower, through a lower level of technological investment. In more specific terms, this mix involves only land-based wind power, hydro, thermo-solar and biomass. In principle, relying on a higher level of diversity in the generation mix will result in several advantages (supply security, promotion of economic activity...) which, in our opinion, are important considerations.

Chart 3.11: Distribution of installed capacity within mix-32.
Total installed power is 81.2 GW, equivalent to a solar SM = 1.8.



Greenpeace 100% Renewables study.

Chart 3.12: Distribution of energy delivery in mix-32.



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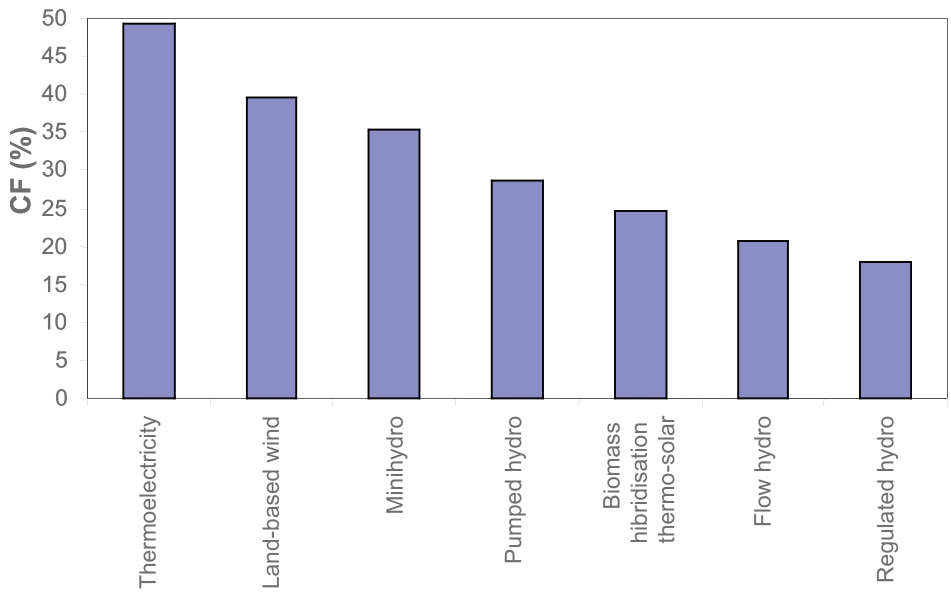
In order to better indicate an improved use of difficult-to-manage renewable resources[12] through the availability of flexibility alternatives in generation, Charts 3.13 and 3.14 show annual capacity factors[13] according to which the various technologies are used as components in mix-32, as well as the quotient obtained from these capacity factors and maximum levels resulting from the application of this technology. As we may note, difficult-to-manage resources such as wind energy, thermo-solar,[14] mini-hydro and flow-hydro are run at close to 100%, maximum level (dissipation near 0 in terms of generation capacity), and flexibility elements within the power system included within the mix model (regulated hydro, hybridization biomass and pumped hydro) are used far below potential levels, which indicates high security reserve levels of supply within this specific mix generation model.

In closing, Charts 3.15 and 16 show the annual hourly distribution of delivered power for the various technologies included in mix-32 in a full-demand satisfaction model.

Chart 3.13: Capacity factors used with the various technologies in mix-32.



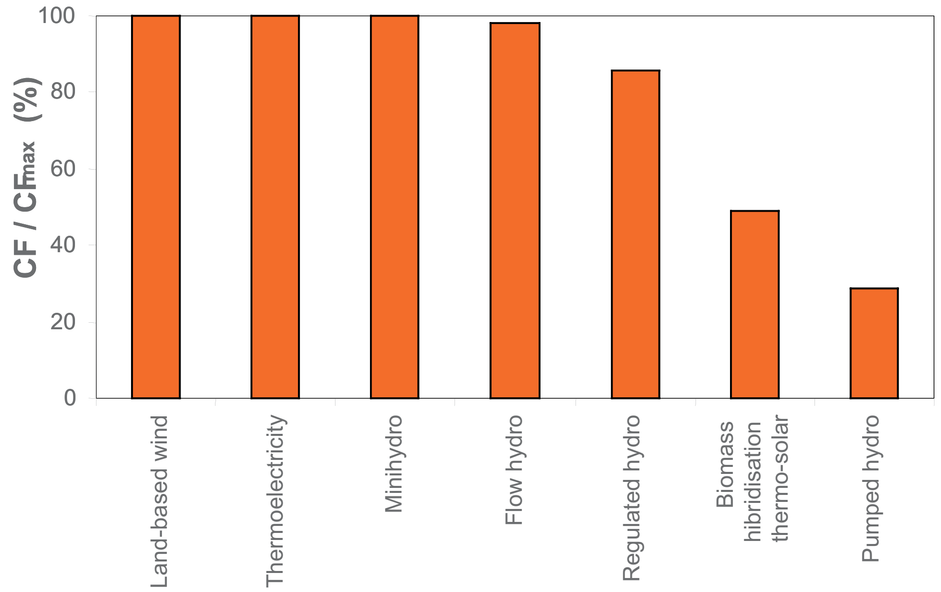
Greenpeace 100% Renewables study.

12 The concept "difficult-to-manage" should be a part of the definition involving a high-range model from the point of view of available power at any given point in time, since low-range models would imply that all renewable technologies are less manageable than conventional technologies in that they allow short response times in terms of power variation.

13 We should mention the relevance of the wind technology capacity factor regarding average values applicable to the existing power pool. This is due, on the one hand, to improved technology mentioned in this paper (to the year 2050), but more particularly to the fact that the process of optimising generation expansion did not make full use of power availability corresponding to the best of the 5 categories in which wind energy was split according to the analysis on potential output as included in the 100% Renewables study. In other words, all wind energy included in this mix falls within levels showing the highest possible wind energy potential. However, the location of existing wind farms as developed in the last 20 years do not necessarily match the best possible locations to be obtained, while wind generator technology shown in these analyses does not necessarily match models used in this paper.

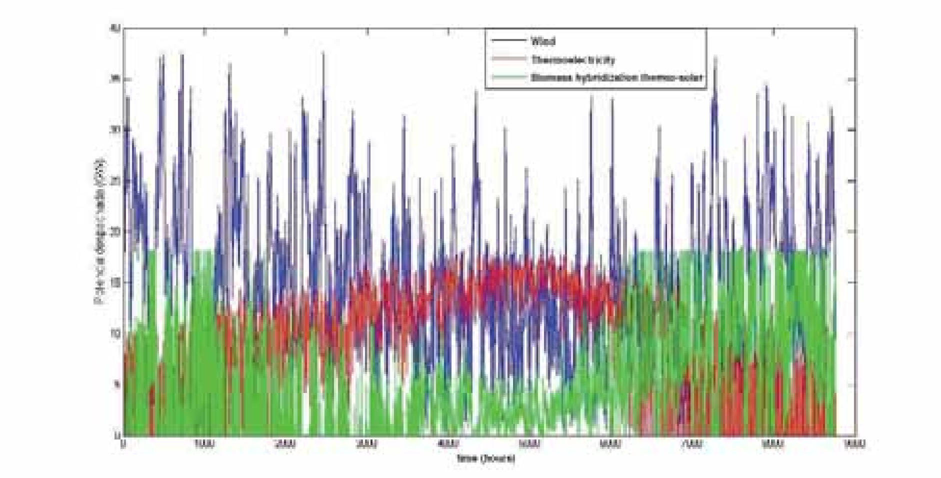
14 Simulations included in this mix do not include management capacity resulting from storage capacity available in thermo-solar plants

Chart 3.14: Relationship between capacity factors governing the use of the various technologies in mix-32 and maximum capacity factors available for these technologies.



Greenpeace 100% Renewables study.

Chart 3.15: Annual hourly distribution of delivered power through wind, thermo-solar and biomass hybridization technologies for mix-32.



Greenpeace 100% Renewables study.

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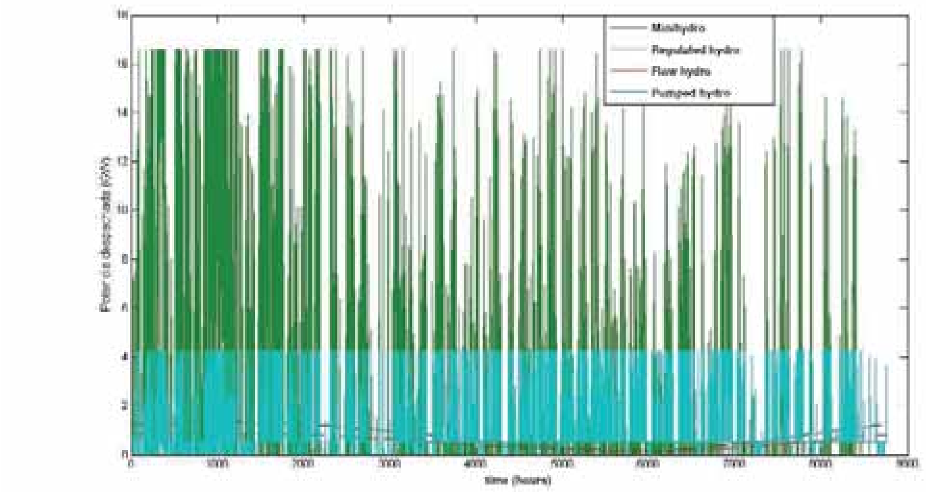
Chart 3.16: Annual hourly distribution of power delivered through the various hydro components in mix-32.



Greenpeace 100%Renewables study.

3.4 Proposed renewables mix scenarios for demand satisfaction

We now turn to three generation mix models based on renewable energy with the capacity to fully satisfy demand within the scenarios included in this paper (high, medium and low ranges) according to results obtained in the 100% Renewables study.

The approach implemented in developing these mix has been to search for a mid-point between a model based exclusively on generation (as some of the mix discussed in the Greenpeace 100% Renewables study, some of whose results are mentioned above) and a second model which also incorporates potential demand management alternatives while retaining technological diversity and responding to restrictions associated with the current status of specific renewable technologies now available within the existing generation framework. The SM values included in this model decrease, when demand is sufficient, to levels found between mix-27 and mix-32 seen above, where operating power values in relation to peak demands periods fall below those of mix-32. Likewise, when discussing these various generation mix models, we have looked to limiting the use of biomass to levels far below potential, in order to make it available for other energy purposes and, in any case, the use of biomass as discussed is derived from hybridization of thermo-solar plants.

We give importance to the fact that the flexibility of te power system is the main tool to facilitate the operation of generation mix models based on renewable energies. As we have discussed above, this flexibility may be reached exclusively through generation (basically by means of high operating power obtained from hybridization of thermo-solar plants and biomass). However, we must bear in mind that this level of flexibility may also be obtained through the demand function by strongly limiting investment requirements for generation. In this sense it becomes interesting to consider the possibility of making use of the major amount available of operating demand, as it can provide a framework for benefitting from demand management in an intelligent network by interconnecting all energy sectors (construction, transportation and industry).

As far as wind energy harvested on land, the highest factor of installed capacity we have been able to include has been 30%, significantly below the level obtained in optimum locations for wind farms (where total power is higher than installed capacity) to reflect the fact that a large part of wind farm locations are conditioned by their historical development.

3.4.1 Generation mix for a High-demand scenario

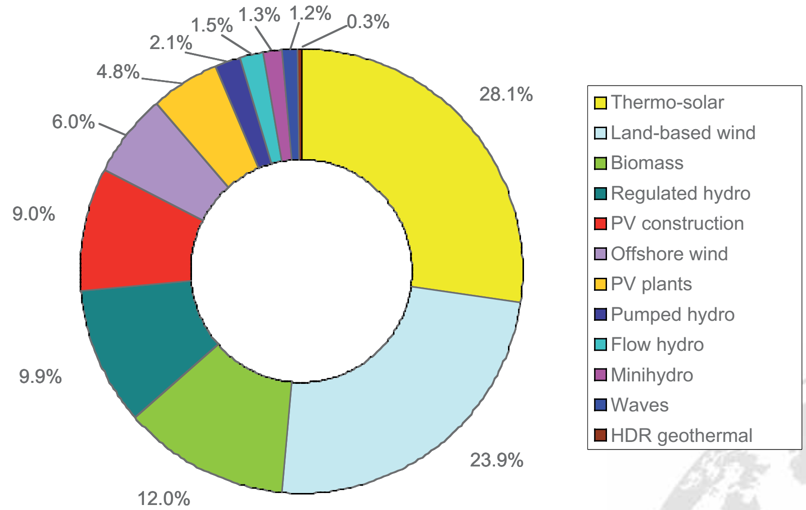
Our proposed mix for a high-demand scenario to reach full demand satisfaction through renewable energy is described in this section. This mix provides 147.3 GW with an SM value of 2.2 for peak demand periods which correspond to hourly demand patterns in the peninsular system for 2003. If we input 20GW through hybridization and biomass provided by thermo-solar plants plus 3.5 GW from hydro pumping, the mix ratio between operating power and peak demand (according to the hourly pattern for 2003) is lower than that of mix-32, and thus requires demand management for thermo-solar power storage (which in this model accounts for 62% of average daily demand), as well as a certain level of input in terms of demand management policies.

Chart 3.17 shows the distribution of installed power in the mix, showing separate values for biomass power (although it is integrated within thermo-solar energy). Chart 3.18 shows the distribution of installed energy without separate values for biomass. Chart 3.19 shows delivery of the various technologies included in the mix required for demand satisfaction.

Annual biomass consumption figures reach 17.7 TWh/yr, some 35% of potentially available residual biomass (Greenpeace 100% Renewables study) and generation obtained from regulated hydro is 18-1 TWh/yr, lower than the potential production for hydro in 2008. Biomass consumption could be significantly reduced by increasing the input of demand management mechanisms.

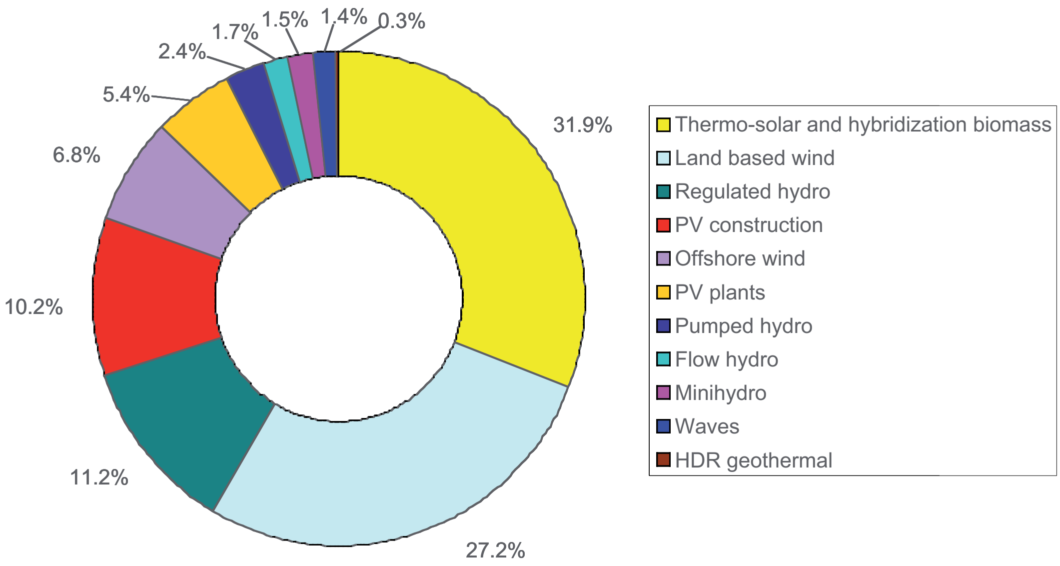
The peninsular surface area covered by the generation sources for this mix is 2.80%.

Chart 3.17: Distribution of installed power for the generation mix meant to cover a high-demand scenario.



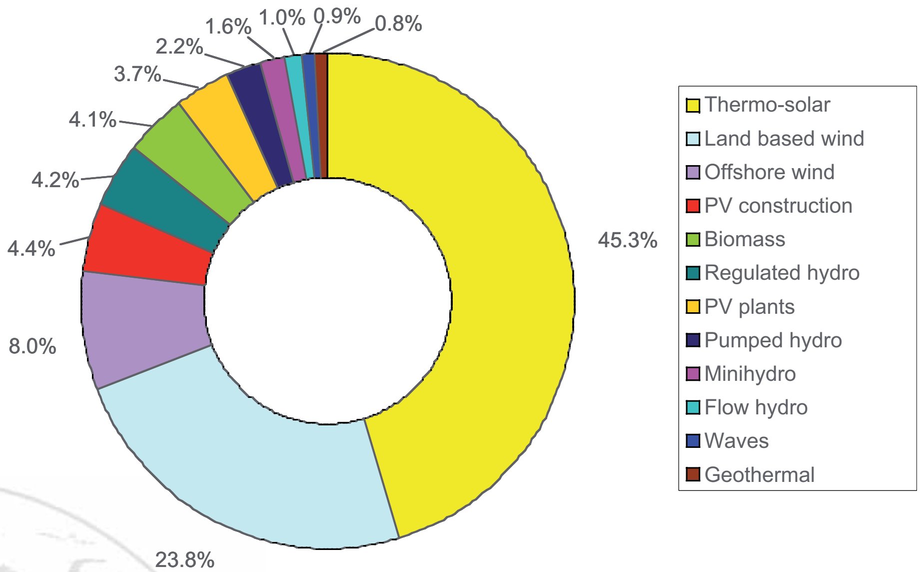
The chart shows biomass as a separate power source although it is integrated as an element of thermo-solar power. Total installed power, independent of biomass, is 167.3 GW.

Chart 3.18: Distribution of installed energy for this generation mix for a high demand scenario.



Total installed power is 147.3 GW for an SM value of 2.2.

Chart 3.19: Distribution of power delivery to satisfy demand through the generation mix aimed for a high-demand scenario.



. Total demand, expressed in b.c., excluding pumping requirements, is 418.3 TWh/yr and 422.4 TWh/yr including said requirements y de 422.4 TWh/a incorporando el bombeo.

3.4.2 Generation mix for a mid-level demand scenario

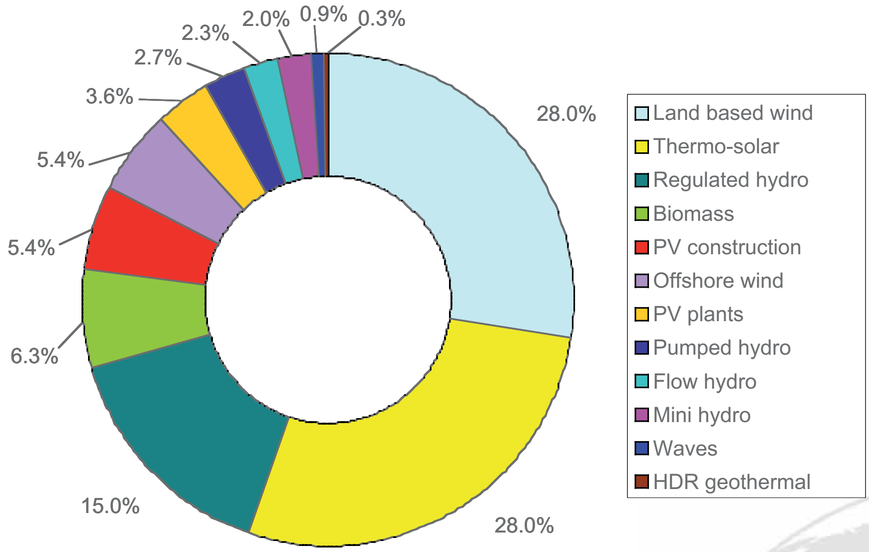
We propose the following mix for total demand satisfaction through renewable energy sources for a mid-range demand scenario. This mix would provide 103.6 GW with SM values of 2.3 for peak demand periods, defined according to hourly patterns of peninsular consumption in 2003. 7GW hybridization with biomass in thermo-solar plants and 3 GW hydro pumping. This mix provides a ratio between operating power and peak demand (according to hourly patterns for 2003) lower than that of mix-32 and therefore requires the input of management capacity resulting from thermo-solar storage (which in this case reaches 61% of average daily demand) and certain demand management policies. A higher SM factor than that of mix-32 (to satisfy the same level of demand) is the result of limiting hybridization of thermo-solar with biomass as well as annual biomass consumption levels.

Chart 3.20 shows installed power distribution in this mix and accounts for biomass input separately (but integrated into thermo-solar sources). Chart 3.21 shows the distribution of installed capacity without a separate biomass component. Chart 3.22 shows delivery through the various technologies included in this mix to guarantee demand satisfaction.

Total biomass consumption in this mix is 6.2 TWh/yr, a 12% of current residual biomass potential (Greenpeace 100% Renewables 2050), while generation obtained from regulated hydro is 16.4 TWh/yr, significantly lower than hydro level potential output for 2008. Biomass consumption could be reduced further by increasing the contribution of demand management policies.

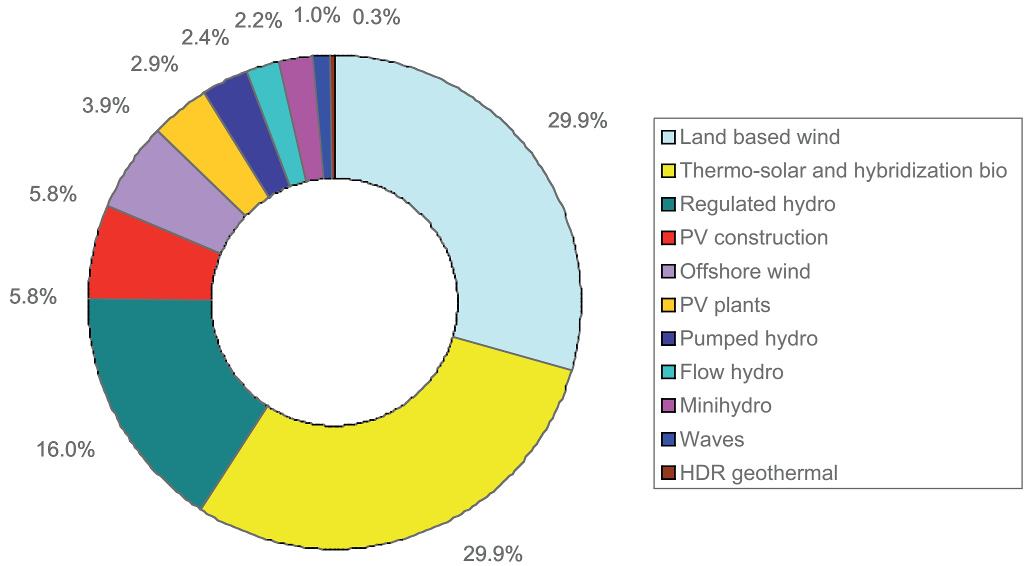
The peninsular surface area covered by the generation pool for this mix is 2.12%.

Chart 3.20: Distribution of installed power for the generation mix aimed to cover a medium-level demand scenario.



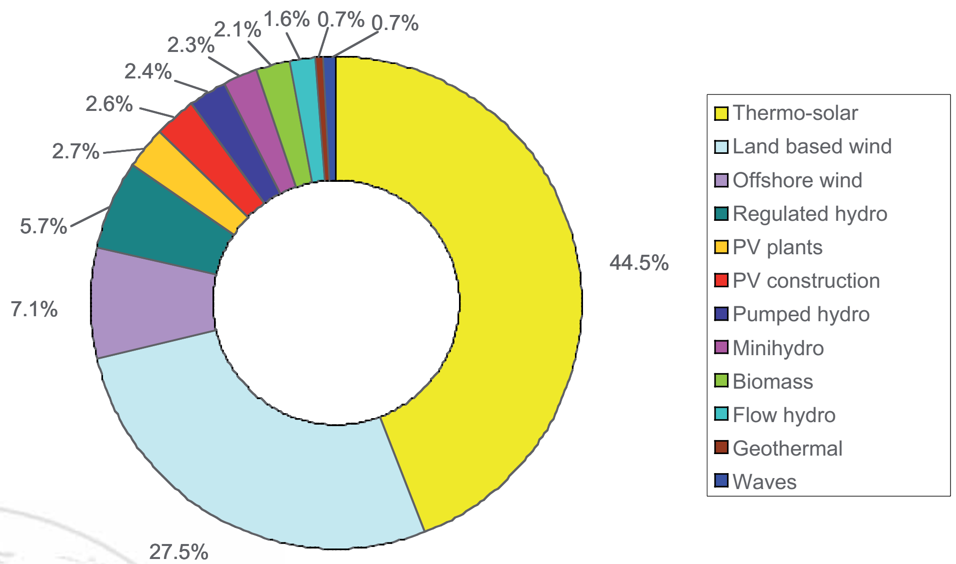
The chart indicates separate biomass figures although it is integrated within thermo-solar sources.
Total installed capacity, excluding biomass, is 110.6 GW- la de la biomasa es de 110.6 GW.

Chart 3.21: Distribution of installed capacity for the generation mix aimed at satisfying a mid-rage demand scenario.



Total installed power is 103.6 GW for an SM value of 2.3.

Chart 3.22: Distribution of power delivery through the generation mix aimed at satisfying a mid-range demand scenario.



Total demand is shown in Bus bars excluding pumping requirements is 280 TWh/yr, and 283 TWh/yr if we include pumping.

The previous mix (full satisfaction for high demand) shows how land-based wind power and thermo-solar are equal, with 31 GW installed power (plus 6 GW offshore wind farms). The reason is that, at these power demand levels, given the existing land-based wind sources and the current rates of growth in this sub-sector will partly determine the future growth of other technologies.

3.4.3 Generation mix for a low scenario

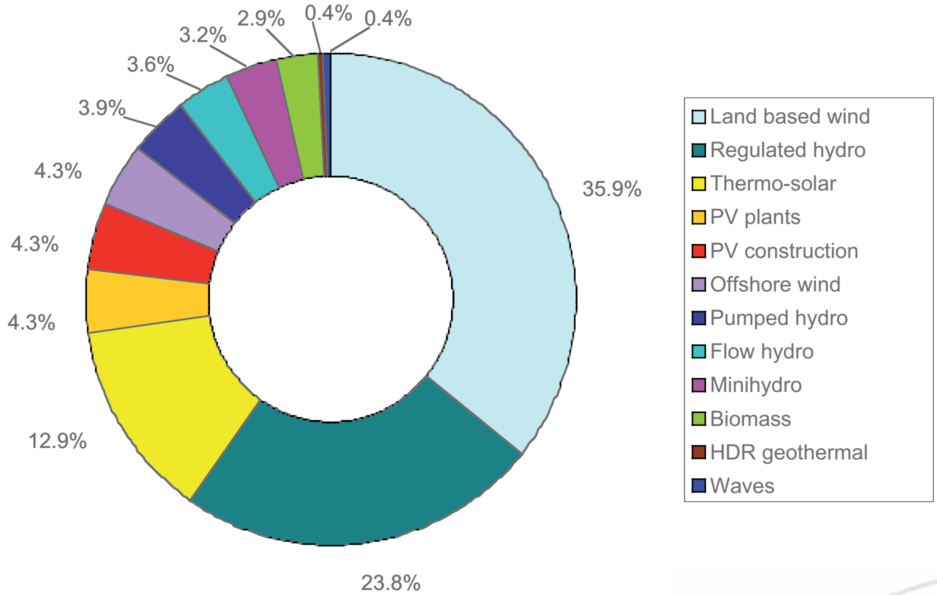
Following is a proposed mix to satisfy total demand through renewable energy in a low-demand scenario. The mix provides 67.6 GW and an SM factor of 2.8 for peak demand levels defined according to peninsular hourly power demands in 2003. Hybridization reaching 2 GW with biomass from thermo-solar plants, and 2.7 GW of hydro pumping, results in a ratio between operating power and peak demand levels (according to hourly values for 2003) higher than those of mix-32, so that it provides the capacity to regulate generation necessary to satisfy demand exclusively through generation. It also provides storage capacity through thermal plants (in this case reaching 32% of average daily demand) and demand management policies.

Chart 3.23 shows the distribution of installed power within this mix and indicates separate values for biomass (although it is integrated within thermo-solar power). Chart 3.24 shows the distribution of installed capacity without specific figures for biomass. Chart 3.25 shows delivery of the various technologies within the mix required to satisfy demand.

Total annual biomass consumption in this mix is 1.8 TWh/yr, which is 3.5% of the residual biomass potential (Greenpeace Renewables 2050 study,) while regulated hydro generation is 17.1 TWh/yr, lower than levels potentially obtained in 2008. Biomass consumption could be increased by improving demand management policies.

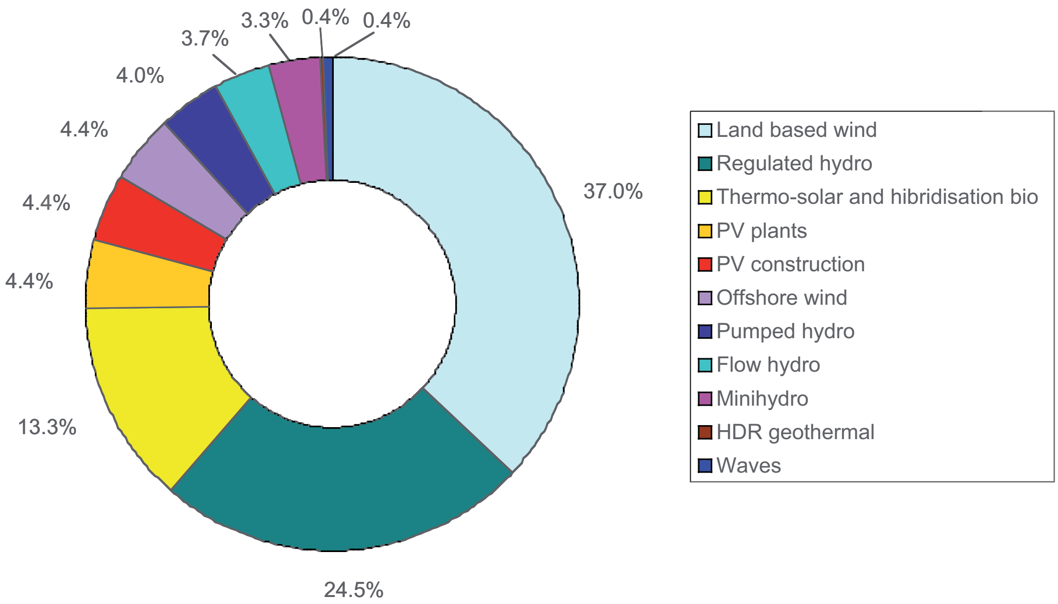
The peninsular surface area covered by the generation pool in this mix is 1.63%.

Chart 3.23: Distribution of installed capacity for the generation mix aimed at satisfying a low-demand scenario.



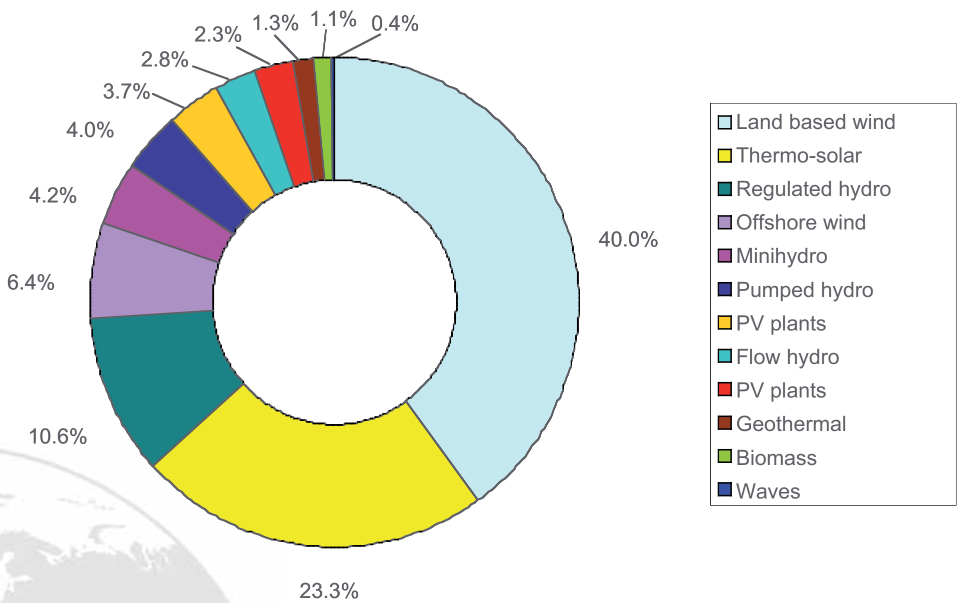
The chart shows separate figures for biomass generation although it is integrated in thermo-solar figures. Total installed capacity, independently of biomass, is 68.1 GW.

Chart 3.24: Distribution of installed power for the generation mix aimed at satisfying a low-demand scenario.



Total installed capacity is 66.1 GW for an SM factor of 2.7.

Chart 3.25: Distribution of power delivery required to satisfy consumption in a low demand scenario.



Total demand, shown in busbar values and excluding pumping requirements, is 152.0 TWh/yr and 154.7 TWh/yr if we include pumping.

The highest SM factor value in this mix as compared to mix-32 (and also to mix 27) results in part from restrictions imposed by the power output of renewable energy currently available and their current annual rate of growth. In fact, the leading component in this mix is a land-based wind power output level of 25 GW (which, at current rates of growth for this sub-sector, should be reached in 4 years or less) while growth in other sources is limited by already developed hydro (a total 24 GW), the presence and rates of growth of PV, and thermo-solar development projects under discussion. In fact, given current power demand levels and the rate of growth in the use of the various renewable technologies, development from current levels through to 2050, according to projected demand figures, would lead to a pool of renewable sources showing total installed capacity higher than the figures included in this scenario. However, this excess capacity would be required in order to satisfy demand during the transition period, and would ultimately be used to satisfy additional demand in other energy sectors not included in this power demand scenario (such as transportation, which in this model shows low levels of electrification).

3.5 Analysis of a schedule of shut-down options for nuclear and fossil-fuel generation plans

The previous sections have shown the feasibility of satisfying power requirements for the year 2050 by means of several generation mix models based exclusively on renewable energy sources. Thus, the transition to these renewable-sourced generation mix models will require a scheduled shut-down of existing nuclear and fossil-fuel elements within the current generation pool.

The priority in this shut-down schedule would be to start closing down nuclear plants given the higher risk involved in maintaining their operations beyond their service life, and also due to the fact that they are by far the least flexible power plants operating in our generation mix and, in a scenario in which renewable energy sources are to play a leading role, the main feature required from the power grid is high flexibility. However, given the CO_2 emission reduction requirements necessary to stabilise the climate, this transition must be undertaken without increasing emissions from the current power generation pool. Within this context, the possibility of shutting down the nuclear component without increasing emissions in the power sector is often subject to question.

This section addresses the options for quantifying the alternatives in scheduling activity in nuclear and fossil-fuel power plants without bringing about an increase in the amount of emissions.

We address three different analyses. First we provide an initial assessment on the basis of installation capacity for renewable sources to be expected over the first, few years of the transition period. We then look at a detailed shut-down schedule scenario based on a mid-range demand level and the resulting generation mix based on the use of renewable sources as seen above. Finally, we analyze the feasibility of a faster shut-down schedule of fossil-fuel plants within the context of this mid-range scenario.

A common element in these three analyses is the mid-range demand level scenario, which includes a mid-level forecast in the size of the population, leading to the calendar of power demand amounts shown in Chart 3.26. A significant component in the development of demand within this scenario is the peak demand level, forecast to come about in 2028. This peak in demand has, as we shall see, important effects on the schedule for shutting down the existing fossil-fuel energy generation pool if the renewable-based energy generation mix we discuss is necessary to cover demand by 2050 (lower demand levels than those required for 2028). On the other hand, this peak demand should have no repercussion on the scheduled shutdown of nuclear plants as long as it begins immediately.

The starting time for this scenario is 2008, when the nuclear, fossil-fuel and renewables pool components currently installed, and operating as they do in this initial year, which is defined as the point of reference. Table 3.1 shows capacity power levels and factors governing the nuclear and fossil sectors in 2008. It is important to note that, for fossil fuels, there are three components with very different levels of installed capacity and of emission amounts. Coal-fired plants showed installed capacity in 2008 amounting to 11.36 GW and running on a CF = 46.58%, fuel/gas plants had installed capacity of 4.42 GW and a CF = 6.34%, and combined cycle plants had installed capacity of 21.67 GW and a CF = 48.38%. It appears obvious that a shutdown schedule for these plants must begin by addressing those which show the highest emission levels and delay shutting down those with lower emissions and better performance levels (combined cycle). Therefore emission reductions will show higher rates than those of fossil-fuel power generation.

Chart 3.26: Forecast for scheduled power demand in a mid-range demand and population scenario.

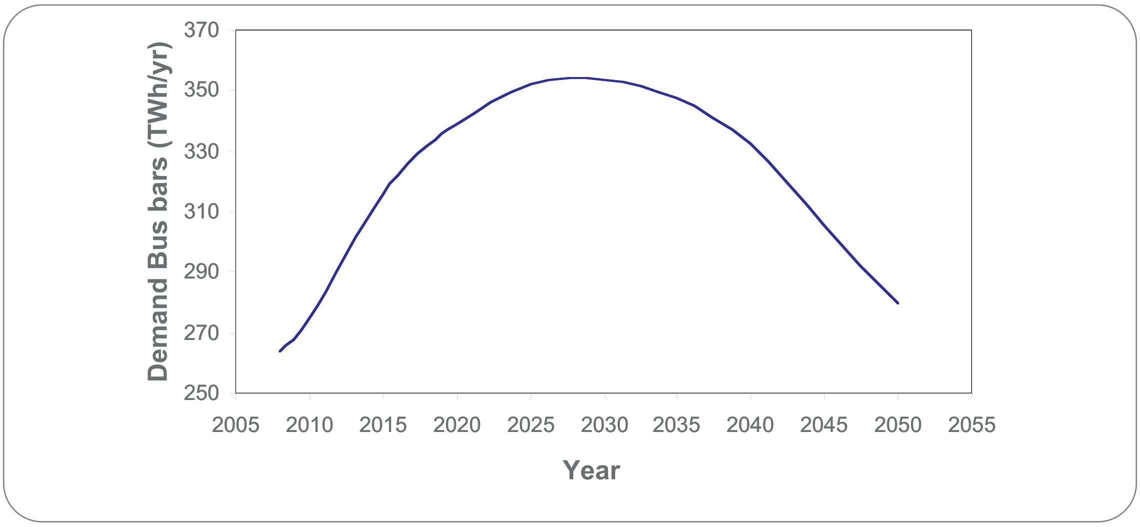


Table 3.1: Configuration and operation of the nuclear and fossil-fuel components of the generation pool in the peninsular power system, 2008.

Generation Pool	Power	Capacity Factor	Generation bc
	GW	%	TWh/yr
Nuclear	7.716	86.93	58.76
Fossil	37.444	42.87	140.62

The prerequisite for developing the following analyses for the shut-down of nuclear and fossil-fuel components of the pool is no increase in fossil-fuel consumption during that process.

3.5.1 Preliminary analysis based on current installed capacity levels

In this preliminary analysis we shall assess the feasible rate of change to be set for a scheduled shut-down of nuclear and fossil-fuel power plants based on current levels of installed capacity in the nuclear component in a setting which excludes regulatory barriers to industrial development and includes only 3 additional renewable technology options besides hydro, that is: wind, thermo-electric and photovoltaic (PV).

Installed wind power capacity reached in Spain's energy sector was 3.5 GW/yr in 2007. A conservative approach would accept future rates of growth of 2.5 GW/yr, fully achievable in the sector if there are no future regulatory barriers to hinder its development.

PV technology reached in 2008 in Spain an installed power capacity of some 3.7 GW/yr. This level of installed capacity was suddenly, and very negatively, affected by Law RD 1578/2008, which has quite mistakenly set important barriers to the permissible level of installation (0.4 GW/yr) and to profits (sudden change in tariffs), as well as additional bureaucratic formalities (registration requirements for pre-allocation of compensation). This unfortunate policy decision will undoubtedly have major repercussions, but for the purposes of this assessment we assume it will be possible to regain power installation capacity in this sector to reach 1.5 GW/yr.

Installed capacity in thermoelectricity shows relatively low current levels, as a result of both the fact that they are still in early stages of commercial development in Spain and of the regulatory limits brought about by the approval of Law RD 661, which sets a quota of 0.5 GW. Nonetheless, on the basis of 10 GW reached through various proposals, it seems conservative to assume installed capacity reaching 1.5 GW/yr.

Likewise, this first assessment includes the assumption of conservative values[15] for capacity factors involved in these three types of renewable technology, as well as the current option mix (PV ground and buildings) and existing technologies. Table 3.2 shows installed capacity and capacity factors for this component.

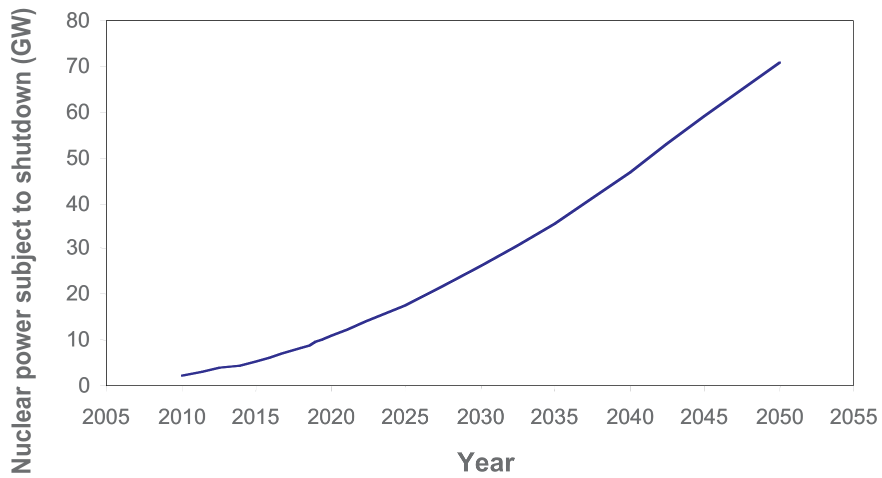
Table 3.2: Tested installed capacity and capacity factors
for the three renewable technologies discussed in this assessment.

Technology	Installation capacity	Capacity factor
	GW/yr	%
Wind	2.5	25
Photovoltaic	1.5	18
Thermoelectricity	1.5	40

This is the framework for the contents of Chart 3.27, which shows accumulated nuclear power —subject to elimination in the forthcoming years— while increasing demand for electricity without increasing the consumption of fossil fuel. As may be noted, within a few years it would be possible to reach levels above those of currently installed as part of the peninsular generation pool and, given a lower capacity factor for the existing capacity factor in the current fossil-fuel component as compared to the nuclear component (approximately one half), excess renewable-sourced generation capacity may be of use in shutting down the fossil-fuel component at twice the speed that the rate of substitution of nuclear power, as shown in the Chart.

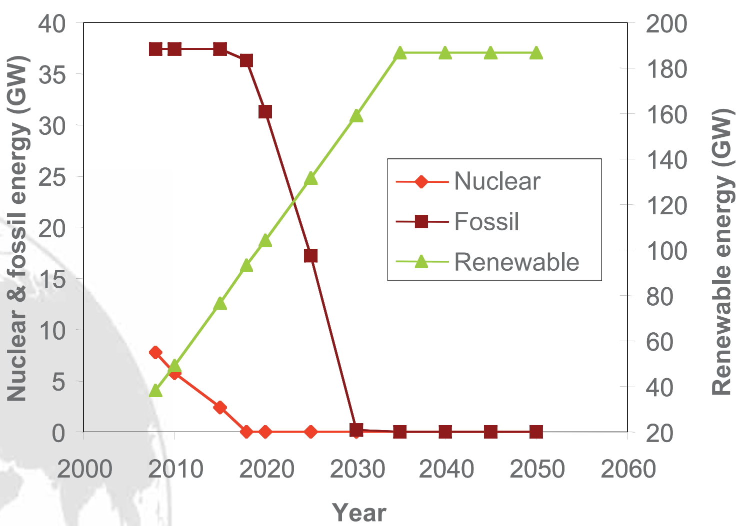
15 This means that, for example regarding thermoelectricity, we don´t consider the hybridization with biomass

Chart 3.27: Nuclear power potentially subject to shutting down in the peninsular system while introducing renewable sources under the tariff scheme mentioned above, while satisfying demand levels in the mid-range scenario without increasing fossil-fuel consumption.



Given these factors, and even within current rates of substitution of power sources by renewable energy, we could consider fully replacing nuclear and fossil-fuel generation pools to significant levels while maintaining demand satisfaction before the year 2050. Indeed, Chart 3.28 shows rates of substitution for the fossil-fuel and nuclear components of the generation pool, and we note how the nuclear component could be fully substituted by 2018, and the fossil-fuel component by 2030. In fact, we may stress the fact that maintaining these rates of installation of renewable sources through 2050 would result in higher total energy levels than the market requires in order to satisfy the forecast levels of demand, with a generation capacity excess of some 335 TWh/yr. This, in turn, indicates there is considerable leeway in the capacity to satisfy energy demand in other sectors which, for the purposes of this assessment, we have assumed will not be powered through electricity.

Chart 3.28: Development of nuclear, fossil-fuel and renewable energy under conditions forecast in installed capacity levels as used in this section.



3.5.2 Detailed analysis, mid range scenario

This section is dedicated to a more in-depth assessment of issues connected with the feasibility of complying with scheduled shut-downs of nuclear and fossil-fuel generation pool components, with a specific focus on mid-range demand and population size scenarios and a proposed generation mix based on renewable energy sources for 2050 as discussed in section 4.

In this analysis we address installed power for 2050 in accordance with the average generation mix levels proposed in section 4. We have also considered the “backwash” effect resulting from the approval of Law RD 1578/2008, which features annual PV installed capacity levels starting from the current 0.4 GW/yr, to be maintained below 1 GW/yr until reaching final target power levels in 2050. As far as other renewable energy sources are included in this generation mix model, we have taken into account growth rates of installed power to match the existing status in each of the technologies under consideration.

Charts 3.29 and 3.30 show a time series for forecast installed power within the peninsular generation system as well as generation associated to each of the energy sources required to satisfy power demand in this scenario to reach 2050 within the nuclear mix configuration discussed in section 4.

As we can see, the nuclear pool will be shut down by 2016, while fossil fuel will be eliminated by 2043 through fossil hybridization in a specific thermo-solar plant.

Chart 3.29: Development of nuclear, fossil fuel and renewables for the mid-range scenario in the “average” renewable generation mix forecast for 2050

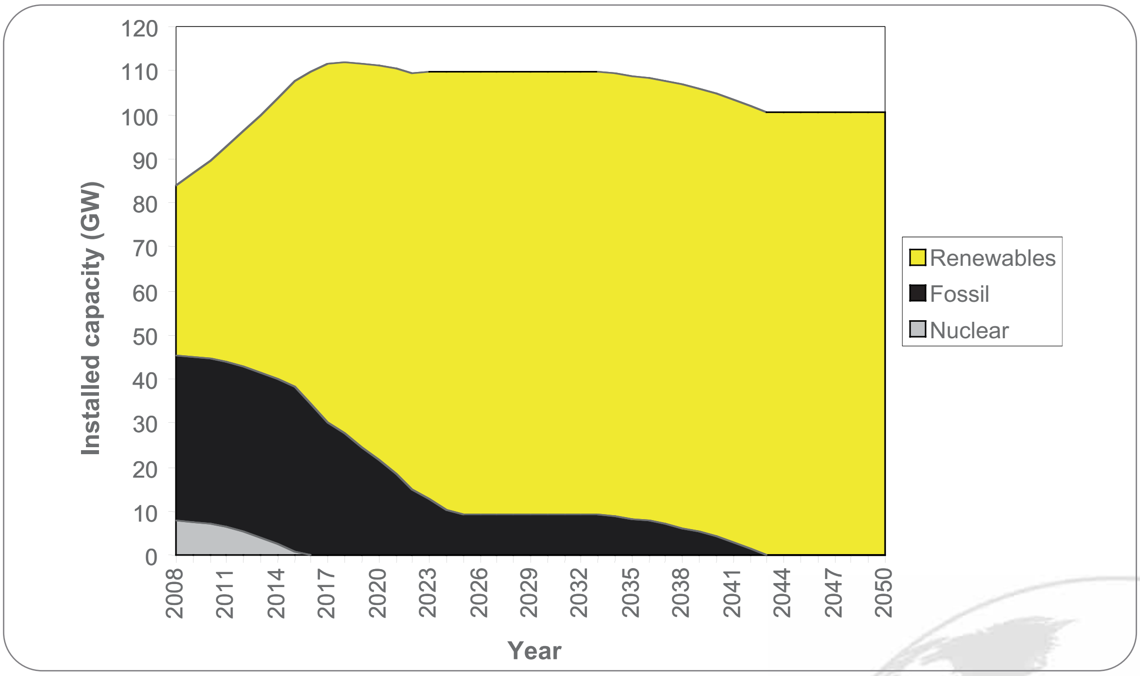
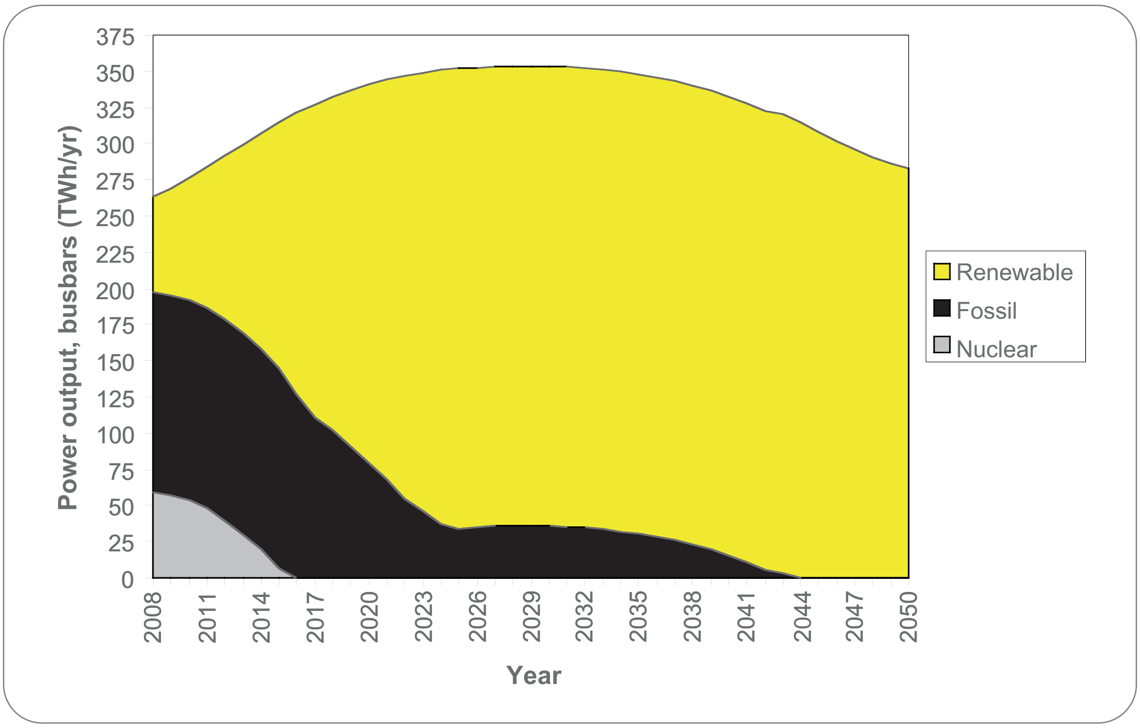


Chart 3.30: Forecast delivery of nuclear, fossil-fuel and renewable generation for the mid-range demand scenario through an "average" generation mix to the year 2050.



The need to maintain a small fossil generation pool component until 2042 and to extend the use of fossil fuel up to 2043 by means of hybridization of certain thermo-solar plants is the direct result of the development of power demand in this scenario, with a peak generation level to be satisfied after reaching the necessary level of renewable energy required to satisfy demand for 2050.

An important conclusion in this regard is the need to start, as soon as possible, a process of shutting down nuclear plants, simultaneously with stimulating growth rates for installed renewable energy power. This process should be completed before reaching areas approaching maximum demand levels, where substituting nuclear generation pool components will be more difficult unless we have been able to reach a sufficiently high level of renewable energy source installed capacity.

The generation mix we propose for 2050 in this demand scenario does not reach the capacity required to satisfy the high levels of demand forecast for around 2030, while renewable generation capacity in this mix could be fully installed at that time. The temporary shortfall in generation capacity, until demand drops to levels forecast for 2050, could be resolved in several ways. These would include, among other options, increasing the implementation of energy efficiency measures beyond those included in this scenario, providing excess capacity in generation through the use of renewable energy in relation to requirements forecast for 2050 (the installed power capacity built into the system would allow for this alternative), hybridization of some of the thermo-solar plants through fossil energy inputs. For the purposes of this assessment we have chosen this last option, and we note that the use of operating capacity through fossil-based energy in hybridization of thermo-solar plants to satisfy the shortfall in generation capacity is marginal if placed in relation with availability (maximum capacity factor included in this option is CF = 1.4%), which is a further indication of the high level of flexibility provided by thermo-solar technology if the need arises to face up to unforeseen circumstances or deviations from demand forecast scenario conditions.

In fact, hybridization of thermo-solar plants with biomass also plays a major role when addressing the need to satisfy the generation / demand imbalance to 2050. Indeed, the renewable-based generation mix proposed for 2050 in this demand scenario includes 31 GW provided by thermo-solar plants, of which 7 GW show the possibility of hybridization with biomass. These 7 GW have a maximum capacity factor of CFmax = 51%, of which no more than CF = 10% is required by 2050. This provides a high level of flexibility in facing up to the transition period and any other contingency or deviation from planned scenarios which may arise.

Chart 3.31 shows the forecast time series for installed power to 2050 included in this scenario. Chart 3.32 shows delivery of energy obtained from each source as required to satisfy demand. This last chart also indicated the leading role played by hybridization with biomass in order to contain fossil fuel consumption during the transition period, including peak demand times for electric power. Finally, chart 3.33 shows the development of the capacity factor for hybridization in thermo-solar plants throughout the period included in this scenario.

Chart 3.31: Development of nuclear, fossil fuel and various other – renewable – technologies for the mid-range demand scenario in the "average" renewable generation mix forecast for 2050.

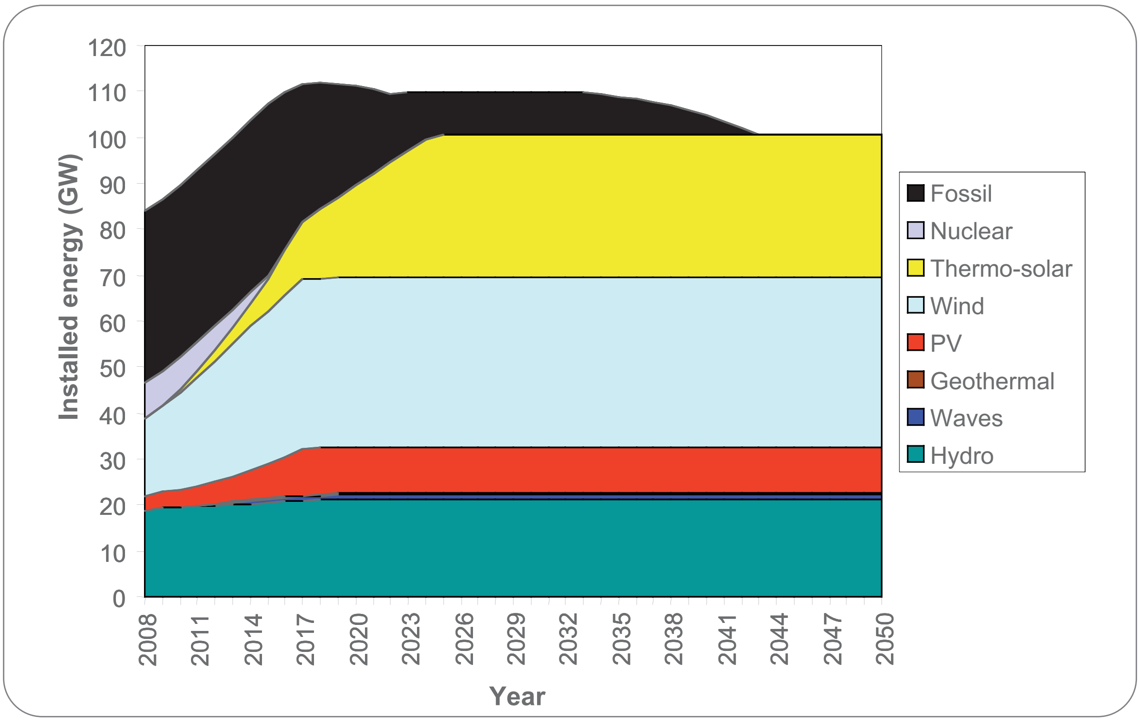


Chart 3.32: Development of nuclear, fossil-fuel and renewable energy power delivery for the mid-range demand scenario in an "average" generation mix for 2050.

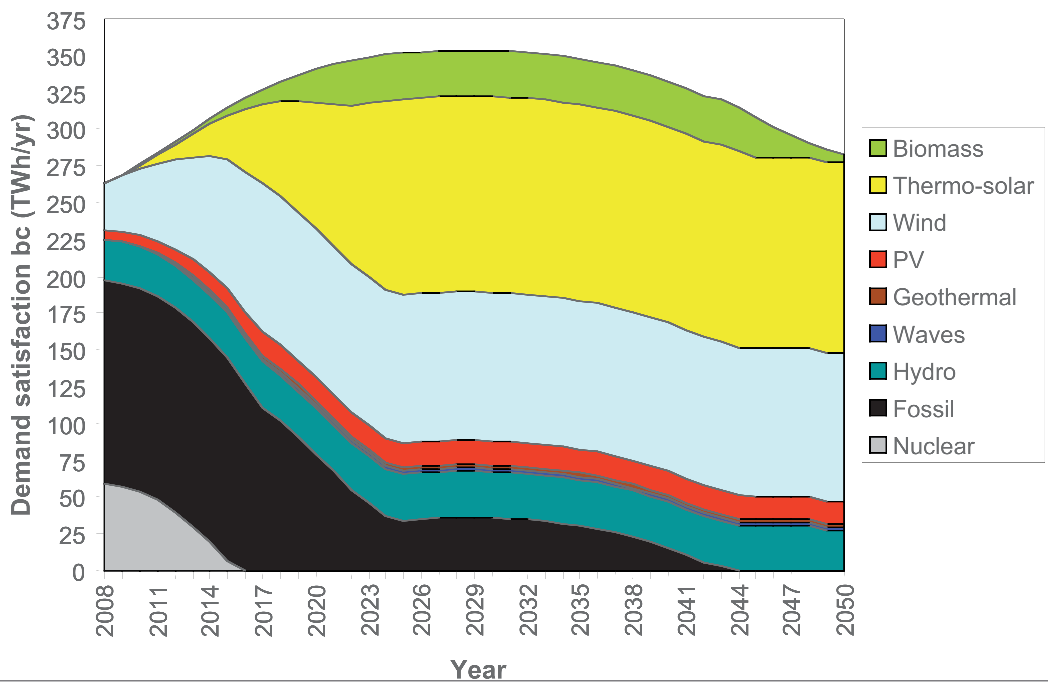
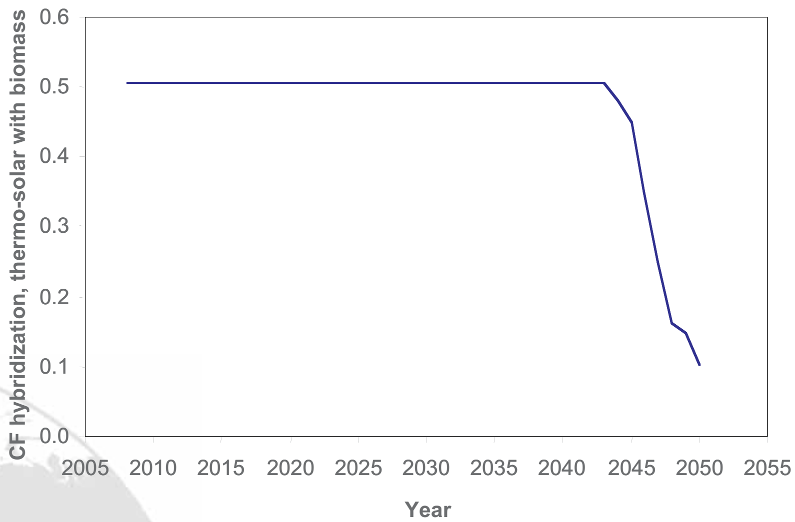


Chart 3.33: Development of the capacity factor through which hybridization with biomass is used in thermo-solar plants throughout the scenario



3.5.3 Faster shut-down rates for fossil-fuel plants

In the previous section, we discussed the feasibility of shutting down the nuclear pool component in a brief span of time within a mid-range demand scenario which includes a time series for the "average" generation mix involved. However, the use of fossil fuel extends through to 2043 as a result of imbalances between the renewable energy necessary to satisfy demand in 2050 and higher demand levels forecast for around 2030 within this scenario. Hybridization of thermo-solar plants with biomass allows for resolving this generation / demand imbalance approximately half-way through the scenario, but limitations in the level of penetration of thermo-solar hybridization with biomass defined in this scenario for 2050 (only 22.6% of thermo-solar plants are considered hybridized with biomass) do not allow this imbalance to be fully resolved through the use of renewable energy.

At this point, we might question the convenience of increasing the number of thermo-solar plants with the capacity to operate through hybridization with biomass. In fact, the increased investment in this subsector is the lowest of all renewable technologies (since it shares the power block with the thermo-solar plant) and biomass intake is limited to a very few years, which could be even fewer according to the rate of introduction of energy efficiency measures.

We now turn to an analysis of a potential mid-range demand scenario by increasing the percentage of thermo-solar plants with biomass to 51.6%.

Chart 3.34: Development of nuclear, fossil and renewable power in a mid-range demand scenario forecast for 2050, with an increased hybridization with biomass of thermo-solar plants to 16 GW of the 31 GW currently installed

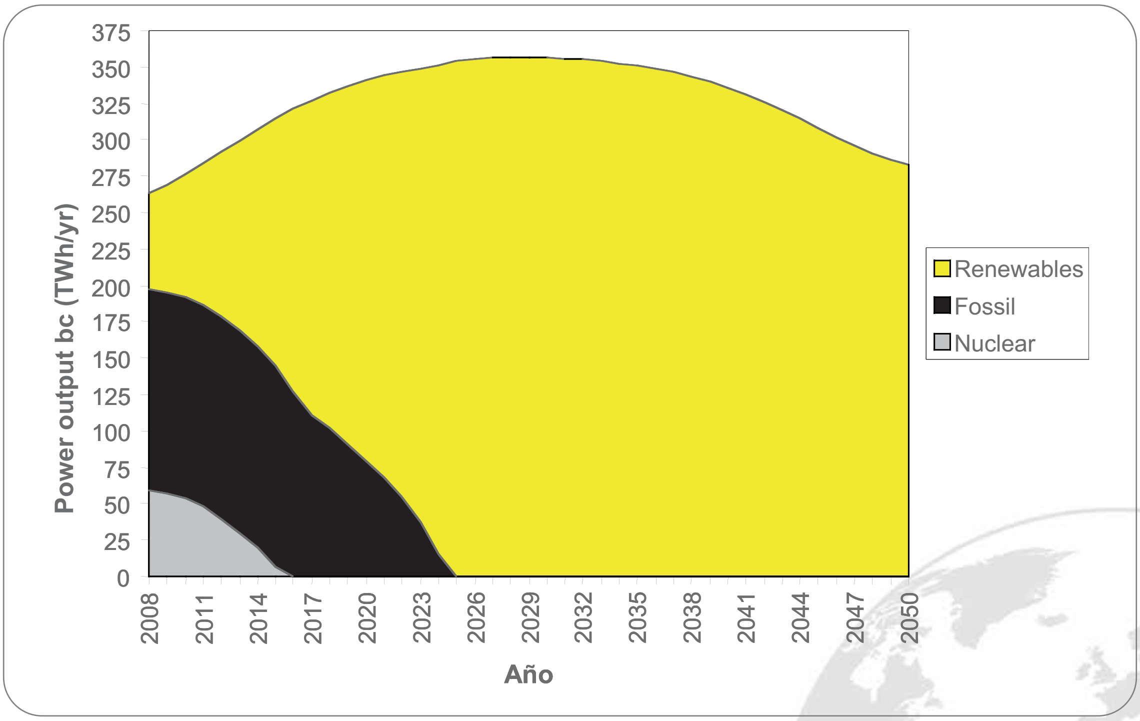


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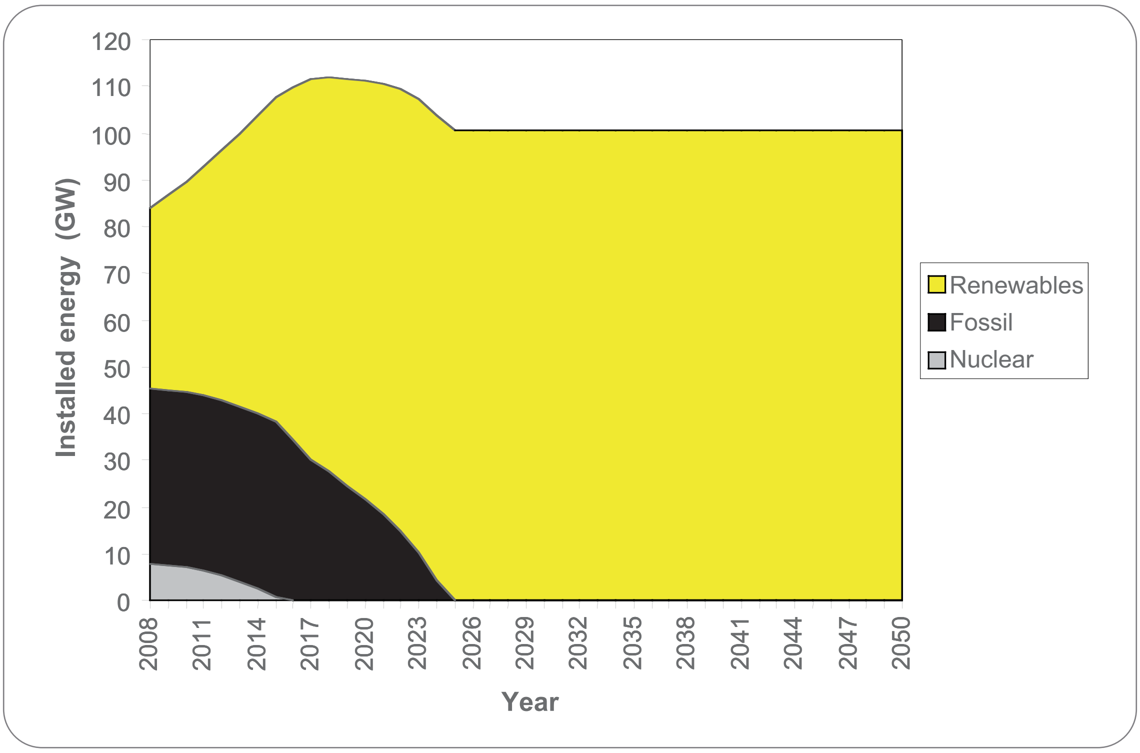
Chart 3.35: Development of nuclear, fossil-fuel and renewable energy delivery in a mid-range demand scenario through an "average" generation mix forecast to 2050, increasing hybridization with biomass of thermo-solar plants to 16 GW of the current 31 GW installed..



As shown in Charts 3.34 and 3.35 nuclear plants could be fully shut down by 2016, and fossil plants by 2025, with no need to make use of these resources for power generation. Thus, it is feasible to accelerate significantly (from 2043 to 2025) the full elimination of fossil fuels for power generation by taking recourse to hybridization of the biomass. However, the schedule of nuclear plant shut downs is not affected by this higher level of penetration of hybridization with biomass since the elimination of the nuclear component takes place before additional thermo-solar hybridization power is fully installed.

Charts 3.36 and 3.37 show the development of installed power as well as the use of various energy resources required to satisfy demand throughout the period under analysis. As we can observe, the generation / demand imbalance during the central part of the period under consideration, where power demand is highest, is satisfied through an increased, once-off use of biomass by hybridizing part of the installed thermo-solar plants.

Chart 3.38 shows the development of the capacity factor under which installed thermo-solar hybridization with biomass power generation is used throughout this period. AS we can see, this power provides significant leeway to face whatever contingency / deviation of the scenario may take place.

Chart 3.36: Development of nuclear, fossil-fuel and renewable resource technology power availability for mid-range demand scenario using an "average" generation mix forecast to 2050, increasing hybridization with biomass of thermo-solar plants to 16 GW of the 31 GW currently installed.

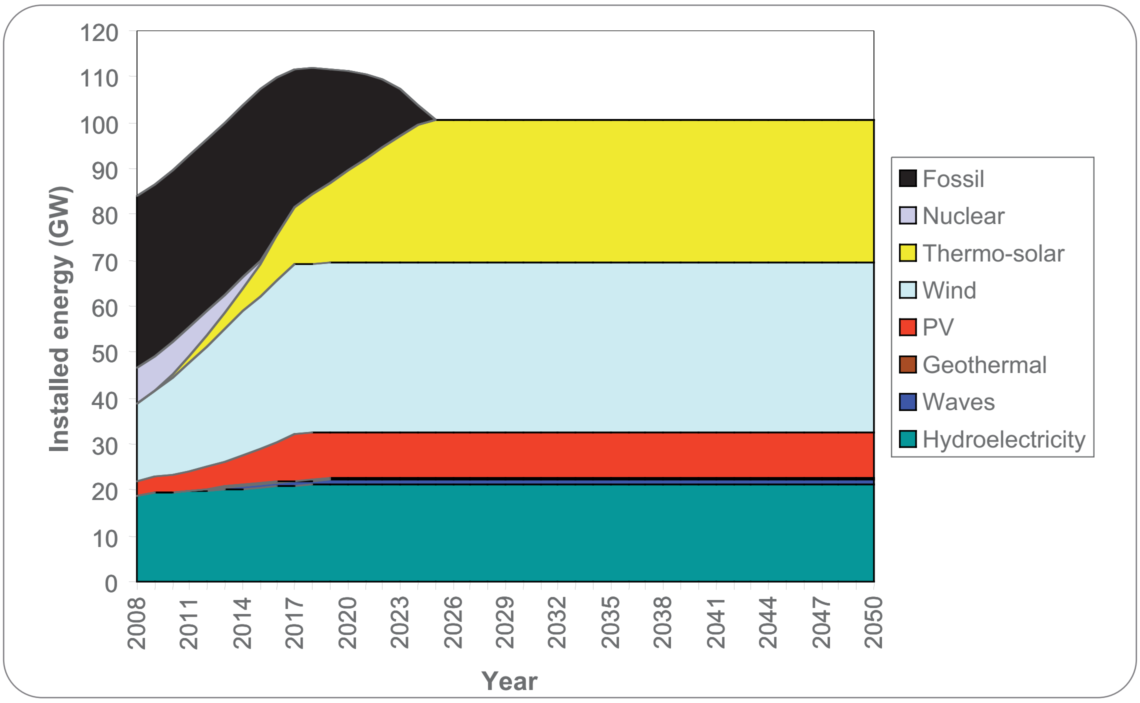


Chart 3.37: Development of nuclear, fossil-fuel and renewable energy resources for a mid-range demand scenario using an "average" renewable generation mix forecast to 2050, increasing hybridization with biomass of thermo-solar plants to 16 GW of the currently installed 31 GW.

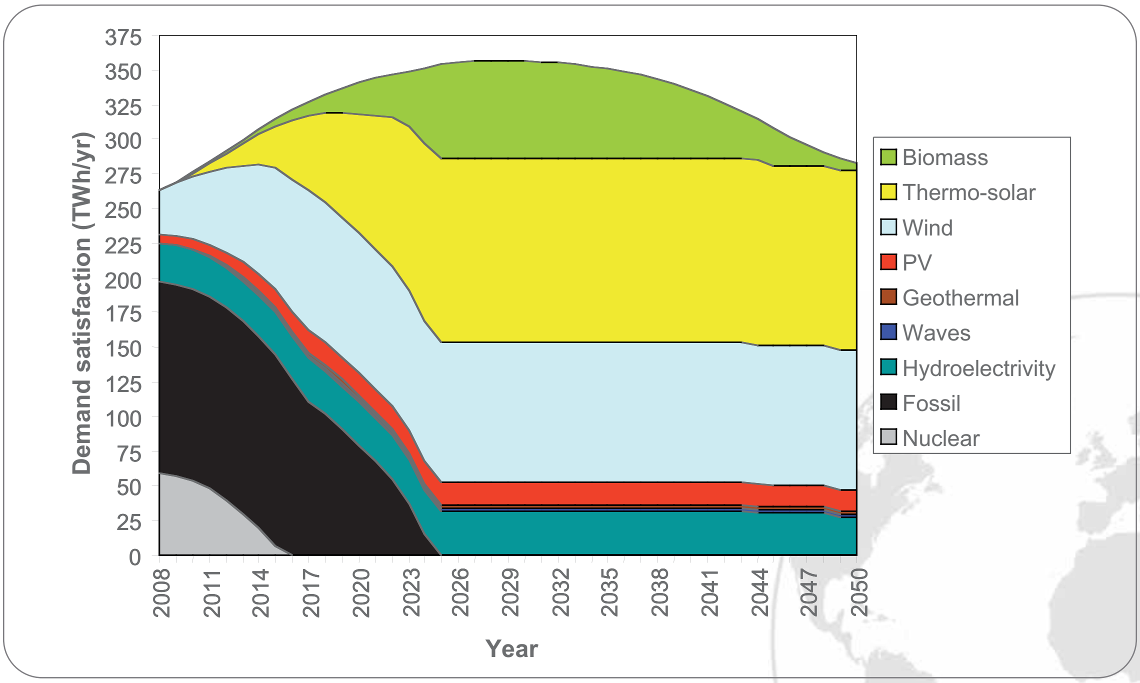


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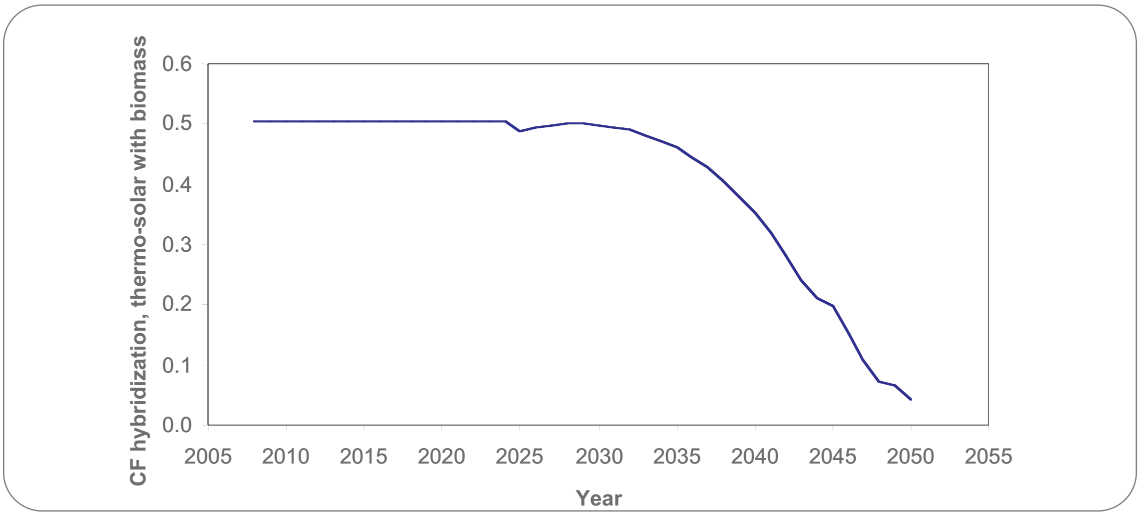
Chart 3.38: Development of the capacity factor under which hybridization with biomass of thermo-solar plants is used through the mid-range demand scenario, increasing hybridization with biomass of thermo-solar plants to 16 GW f the currently installed 31 GW



Lastly, by way of example illustrating renewable power installation requirements necessary to reach this scenario, Chart 3.38 shows the annual behaviour of stored (accumulated) power and installed power in thermo-solar and biomass (hybridization of thermo-solar), which should undergo the fastest rates of growth in this scenario.

As we see, based on low rates of annual installation for these technologies, required performance would lead to peak installation rates of some 3 GW/yr at approximately 2015 for thermo-solar technology.[16] Biomass hybridizing thermo-solar power would have a later take-off point and reach peak annual installation rates[17] at around 2025 in order to be ready to take on the peak power demand forecast in this scenario.

Maximum annual installation rates for thermo-solar[18] plants remains below maximum rates for the wind and PV alternatives already known in Spain (respectively 2007 and 2008), so that this segment of the scenario should meet with no limitation as far as the sector is concerned.[19] However, it is important to stress that restrictions and regulatory barriers in the shape of power quotas for installation, or other hindrances and uncertainties associated with bureaucratic or administrative requirements may indeed have a significant negative effect with rates required for achieving this type of new sector deployment. Therefore, and given the experience undergone in Spain in terms of commercial growth in such technologies as wind or PV, we may conclude that regulation is the basic link to make these scenarios viable and feasible, particularly in the early stages of development, when it is fundamental to ensure that regulation is implemented responsibly, and aiming at short- and mid-term objectives.

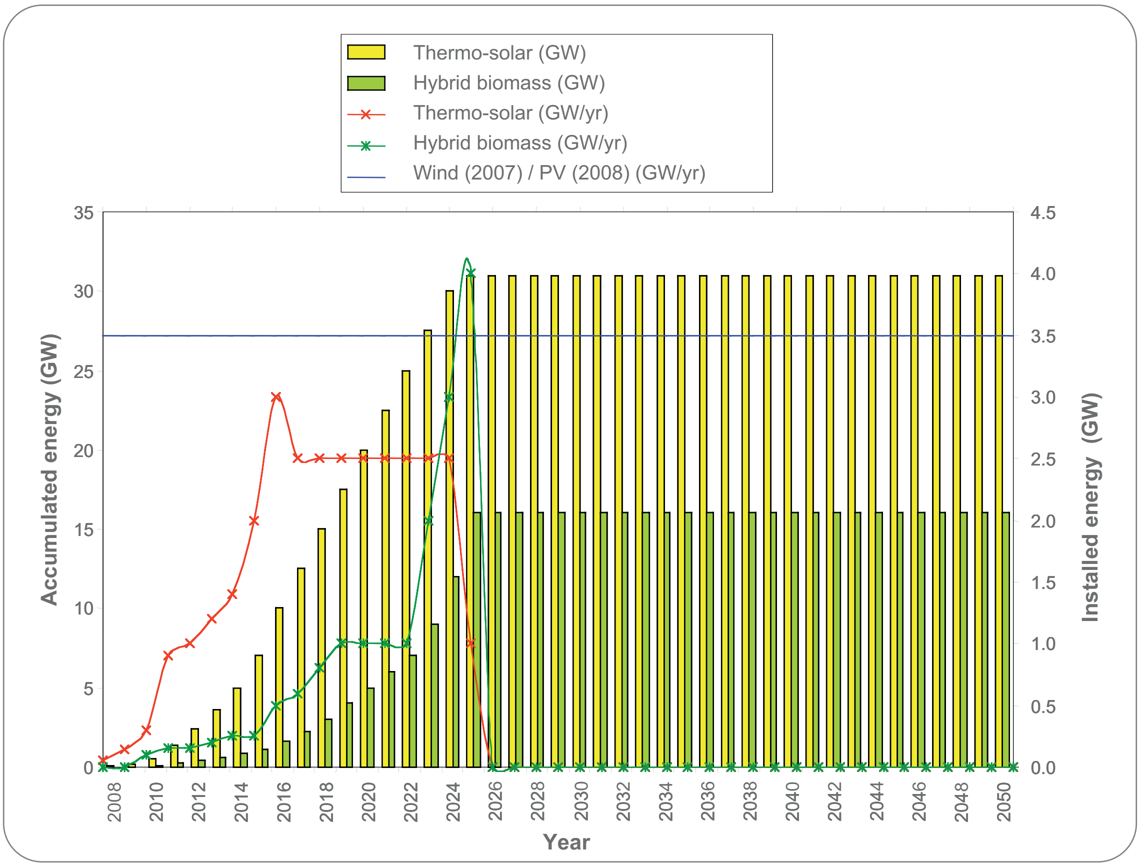
16 It is important to stress the fact that these maximum levels in installation rates do not match the potential obtained at the end of this industrial activity, since this sort of deployment would in Spain do nothing but set the bases and place our industry in an extremely favourable condition towards international markets in developing this technology within a much longer time span than considered in this paper required to develop the generation mix in Spain.

17 We should consider that regarding biomass hybridizing thermo-solar plants, the installation of equipment and construction/procurement required is very small as compared to thermo-solar since they share the power block with a thermo-solar plant. It is thus only necessary to adapt the support boiler unit to its thermo-solar counterpart, supply of biomass, and add elements for converting the bio-fuel to be used

18 Since biomass is a complement to thermo-solar plants the existing level is much less critical

19 Although it is true that concerning thermo-solar the sector should re-organise itself in order properly to face up to this challenge.

Chart 3.39: Development of thermo-solar and biomass hybridizing thermo-solar capacity required to pursue this scenario.



3.6 References

CNE, 'Régimen especial de producción de energía eléctrica en España. Informe mensual de ventas de energía del régimen especial', enero 2009

EC, Directorate-General for Energy and Transport, *'European energy and transport trenes to 2030'*, enero 2003

García Casals X., Domínguez Bravo J., Linares Llamas P., López García O. *'Renovables 2050: Un informe sobre el potencial de las energías renovables en la España peninsular'*, Greenpeace, julio 2005

García Casals X., Linares Llamas P., Santos Pérez F.J., *'Renovables 100%: Un sistema eléctrico renovable para la España peninsular y su viabilidad económica',* Greenpeace, octubre 2006

Greenpeace, *'Energy [r]evolution: A sustainable global energy outlook'*, Greenpeace, EREC, octubre 2008

IEA, *'World Energy Outlook 2007'*, 2007

IEA, *'Empowering variable renewables: Options for flexible electricity systems'*, 2008

INE, Universidad de Sevilla, *'Tendencias demográficas durante el S. XX en España'*, marzo 2004

INE, *'Proyecciones de población base censo 2001'*, marzo 2009

IEA, *'World Energy Outlook 2007'*, 2007

REE, *'El sistema eléctrico español. Avance del informe 2008'*, diciembre 2008

4 Ideas for petroleum-free transport in 2050 [1]

"A sustainable transport policy should face up to growing traffic volume and congestion, noise and pollution, and promote the use of means of transport less harmful to the environment as well as the total incorporation of social and environmental costs. Action is required in order to reach a complete break between growth of transport and of GDP, particularly by means of change in transport modes – from road to rail, sea-borne traffic and public passenger systems" (European Strategy for Sustainable Development)

A View of transport in 2050

Mobility potential based on electric engines, renewable energy and an intelligent management system

The following takes place in the year 2050. We assume that, by that time, the transport system is fully computerized so as to optimize resources and the vehicle pool, there is no need for drivers, all vehicles run on electric or hybrid engines (the latter on a small combustion engine using sustainable bio-fuel to recharge batteries), and 100% of electricity is provided by renewable energy sources. The Integrated Transport System (ITS) is the platform responsible for providing mobility for people and goods.

Carlos was traveling to a family dinner at his grandparents' house who live in the same city, some 6 kms away. He walked up to his home's interactive panel, told it to turn on, and said:

— I want to go to Honduras Street and be there by 10 AM.

The panel voice answered:

— Shortest route or less expensive route?

— The less expensive, I have enough time.

— At present there is a 20-seat public transport scheduled to travel near this residential unit at 9.20, reaching the residential unit stop at 9.55. The cost is 5.2 Euros. At pick-up time the transport unit will be carrying 15 passengers. It is electric, charged by 50% wind energy, thermo-solar 30%, hydroelectric 10%, and stored from various sources 10%. (All data and the map for the trip appear on screen).

— I accept, please reserve.

— Request completed. Would you also like to purchase the return ticket?

— Yes, I need one for three passengers traveling from Honduras Street, number 27 back to this residential unit to be here by 18.50. I need the fastest possible route.

— The SIT suggests you reserve a four-passenger transport unit, leaving one seat free. Collection time is 18.30. The cost is 60 Euros, or 70 Euros if you reserve the entire vehicle.

— That seems very costly, it would normally come to about 50 Euros. What is the reason?

— The price is higher than average because the system has committed 75% of traffic capacity for that time of

1 The author of this chapter is Heikki Willstedt Mesa in collaboration with Alejandro Moratilla Torregrosa.

the day. Besides, the ITS informs us that the only vehicles available are hybrid with bio-fuel rather than fully electric. Would you like me to search for a less expensive, slower option?

—No, reserve that transport unit.

—Request completed. Will you need an audible reminder before the forward journey?

—Yes, at 9.00 hours.

—Reminder programed for 9.00. Anything else?

—Nothing else. Goodbye

The interactive panel switched itself off, and Carlos was left wondering about the expense involved in travelling to watch the game with his cousins after eating at his grandparents' house.

This scene involves a combination of current technologies: interactive panels, route searching systems, renewable energy and computer/GPS guidance systems, running on hybrid-electric engines. In order to bring this scenario to life it would be necessary to improve all these components so as to optimize their use and integration and, something not yet available, to create a platform for computerized integration of transport to allow for managing renewable energy resource in accordance with the mobility function required by society. This would lead to a system based on payment for mobility according to supply, demand and energy availability.

4.1 Introduction

The story of our civilisation could not be written without mentioning the revolution which has taken place in transport over the last 200 years. Since the days of travel based mainly on animal traction and the force of winds, with limited capacity and speed, we have reached modern transport systems involving billions of users and billions of tons of goods, traveling at speeds unimaginable in the 19th century.

This revolution has been possible as a result of the presence of the combustion engine applied to all modes of transport (land, sea and air). The growth of this technology throughout the 20th century has been possible due to the wide-ranging availability and relative abundance of a specific energy resource, petroleum. Its properties, including especially energy density and a liquid state, have placed it, for practical purposes, as the foremost, and almost single, source of energy used in transport.

This total dependence on a single resource, petroleum and by-products, makes transport a sector of the economy that is more vulnerable than others, in the short term, on shifts in price levels, while in the long run it must face up to deep re-structuring as a result of the inevitable depletion of its main source of energy.

On the other hand, our society's mobility also brings about significant environmental repercussions, mainly greenhouse gas emissions leading to climate change, along with health-related problems resulting from pollution, particularly in urban areas, and accidents. By way of example, the EU has calculated that traffic jams in major cities account for financial losses reaching 1% of European GDP figures[2].

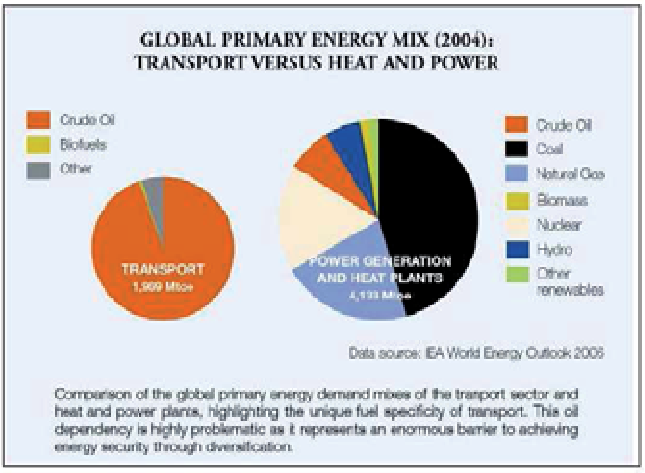
Within an energy scenario up to 2050, the transport sector will require alternatives in the areas of energy, technology and management in order to solve these two major challenges it faces: total depletion of its main energy resource, and decreased effects on both the environment and the population.

2 According to the INFRAS (2004) report, negative financial figures for Spain resulting from transport jams and general congestion in 2000 may have reached levels equivalent to 5-8% of GDP, depending on the system used in calculations.

4.2. Current transport framework and short-term conditions

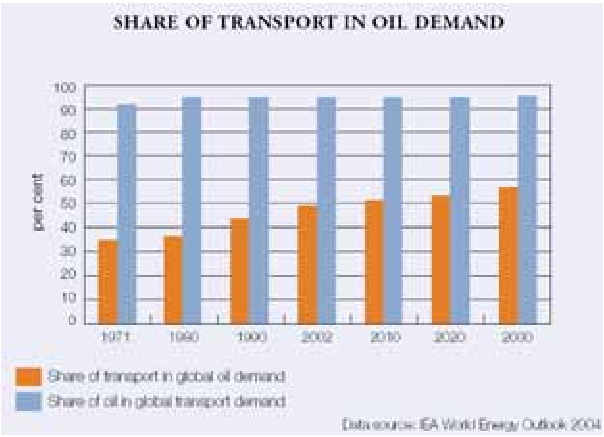
4.2.1 The world runs on petroleum. For how long?

Chart 4.1 World-wide energy consumption and transport-related components



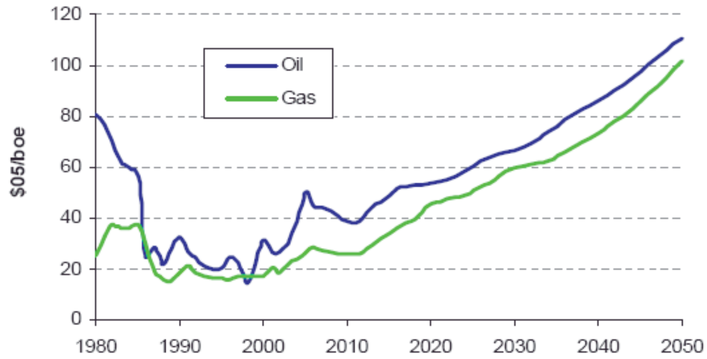
At present, approximately one/third of global energy consumption is taken up by the transport sector. Of this one-third, 98% is petroleum by-products such as gasoline, gas-oil, kerosene and fuel oil. This is one of the few sectors of the economy in which a single energy source accounts for an almost total monopoly.

Chart 4.2 Share of transport in global oil demand



The existing vehicle fleet is approximately 800 million units world-wide, which could double by 2030. We cannot continue ignoring the implications which arise from the high level of dependence on liquefied petroleum by-products. Given the latest IAA analysis regarding the rate of increased oil consumption and the rate of depletion of the major existing oilfields (WEO 2008) one can but agree with the conclusion that, once the current economic crisis will be overcome, it is probable that the 21st century's second decade will undergo a crisis in the availability of liquid fuel (not necessarily an energy crisis) as a result of substantially lower supply levels than global demand would require, which in turn could lead – in economic terms – to increased oil and oil by-product prices as disruptive to the world economy as those of 1973.

Chart 4.3 Price time series, oil and gas, plus forecast to 2050 according to the EU scenario mentioned in the text.



Source: EU, WETO-H2 Project

A second element conditioning the future of the transport sector is the concern regarding its world-wide environmental effects, in particular the agravation of global warming, due to greenhouse gas emissions generated by the combustion of oil by-products (the transport sector is the source of 28% of greenhouse gas emissions in the EU) and due to local impact, especially in cities where polluting gases generated by vehicles are the cause of significant health problems for the population and bring about major traffic jams, with the resulting economic implications.

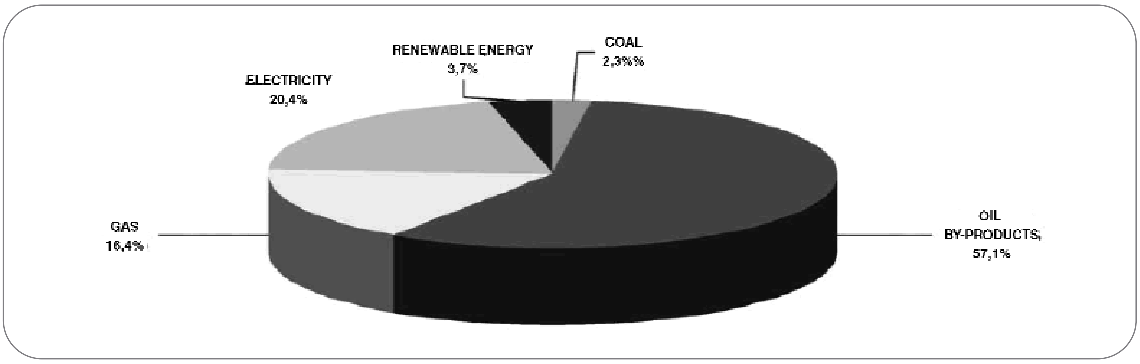
These are two major challenges wich are movilizing the international comunity to find solucionts: reducing the level of dependence on oil and its environmental and social impacts. Thus, both the IEA and the EU, as well as various national governments – among which are the USA – have drafted, or are drafting, plans involving different scenarios with the purpose of establishing Road Maps towards substituting the role played by oil in the transport sector.[3]

3 By way of example, Sweden has initiated a government action plan with the purpose of doing away with transport-related oil by-products by the year 2020.

4.2.2 Spain's transport sector. Significant economic repercussions alongside indications of saturation and basic environmental effects

The strong growth of Spain's economy over the last 15 years has been possible as a direct result of an increased energy input in the transport sector. However, growing demand in the recent past for transport of persons and goods, particularly road traffic, seems to approach a saturation point which continued investments in road infrastructure are apparently incapable of resolving. This situation is strikingly obvious in urban areas as well as in city access and ring-road systems. Between 1990 and 2008, Spain's vehicle fleet grew from 16.5 million to 31.5 million units, a growth of 91%. Over the same period, the consumption of oil and by-products addressed to the transport sector has grown by 124% (MITYC, SGE).[4]

Chart 4.4 End-user energy consumption, Spain, 2007



The transport sector currently accounts for 38% of Spain's total energy consumption, with practically all sources depending on oil by-products (95%). At the same time, approximately 55% of total national oil demand is derived from the transport sector, while 20% of demand is generated in the industrial sector, 8% in industry and 17% in housing and others.

Over the last two decades, one of Spain's main energy policy objectives has been resolving the country's energy dependence: 80% of Spain's energy consumption is imported, as compared with an average 50% in the EU-15. Net crude oil imports account for approximately 4% of Spain's GDP (CORES, INE, 2009), compared with levels of some 1 – 2% in most European countries.

On the other hand, greenhouse gas emission levels in Spain have increased beyond both EU average levels and far above targets pre-established for the Spanish market in accordance with the terms of the Kyoto Protocol. Greenhouse gas emissions in 2007 were 52%-60% above those of 1990, while it is the target for 2012, not to exceed this levels by more than 15%.[5]

The transport sector, within the economy, has tripled energy demand over the last 30 years. Since 1990, this sector has doubled CO_2 emissions and has become the sub-sector which has contributed, more than any other, to increasing greenhouse gas emissions in Spain above target levels defined within the Kyoto Protocol.

4 We may extrapolate from the figures quoted that energy efficiency in the Spanish vehicle fleet has significantly decreased, but this analysis would require the input of additional factors, such as distances traveled, in order to valídate the above mentioned values.

5 Data obtained from the Inventory of Atmospheric Emissions in Spain, Ministry of the Environment and Marine and Rural Areas, 2009. In fact, compliance with target levels is calculated by establishing the average level of emissions for 2006-2012.

4.2.3 Challenges facing Spain's transport sector

Past energy crises have shown how an important increase in oil fees paid by countries such as Spain, where 95% of oil and by-products are imported, may have significant repercussions on the national economy, particularly by multiplying transport costs. The most recent data published by the MITYC net oil payments for 2008 reached 44,500 million Euros, equivalent to 4% of GDP. [6]

In order to avoid possible crisis linked to rising oil prices and limitations inherent to the fight against climate change, Spain must face the challenge to act in accordance with the following core ideas:

- Reduce the demand for motor transport, particularly in cities.
- Develop and implement a transport system which allows for the use of renewable energy sources.

Reducing the demand for transport is the single political option which may mitigate all negative effects, including economic and environmental or social repercussions. One of the main areas in which it is possible to efficiently regulate transport demand is planning land use. The integration of policies which place the priority upon reducing private transport in urban development plans, may lead to avoid a large number of motorized trips and reduce their distances. In order to do, it becomes mandatory to avoid low-density residential urban development without services and to favour instead mixed multi-purpose models (productive residential areas) including related services.

On the other hand, in order to achieve a transport system which may involve eliminating oil dependence, it becomes mandatory to improve the efficiency of combustion engines and to diversify, both in terms of technology and in the sources of energy required.

Alternatives available towards a strategy based on diversification

1. Improvements in combustion technology.

The decrease in the size and weight of new vehicles, introduction of streamlining improvements and efficient auxiliary components, reduction in speed limits and tyre resistance to friction, or simply hybrid engines, may improve the efficiency of vehicles powered by combustion engines. These improvements, however, may achieve no more than approximately 20% in terms of reducing fuel consumption (BCG, 2008).

2. Substituting fossil fuel by similar, vegetable fuel.

So far, the main alternative investigated regarding potential substitute energy sources has been the use of bio-fuel which, given its liquid nature, is amenable to allowed for a similar use as compared to fossil fuel. Nonetheless, concerns have arisen regarding the sustainability of major global growth in the use of this alternative due to the effects on agricultural prices and increasing deforestation in tropical countries. These factors have hampered the industrial development of these fuel sources in many countries, including Spain.

3. Changes in technology and energy sources.

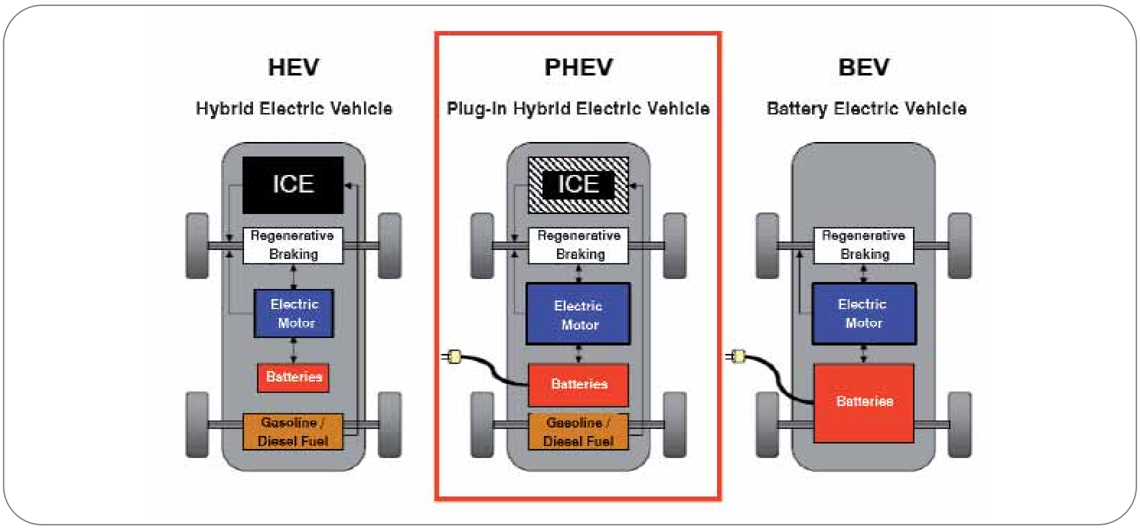
After some early enthusiasm shown by the automotive sector concerning the possibility of using hydrogen as alternative energy source, its development has recently become markedly slower as a result of a number of issues which place doubt on its short-term viability.

6 The cost of energy in 2007 reached 33,180 million Euros, which grew by 34% in 2008. On the other hand this year, after the collapse of oil prices, energy cost could drop below 2007 levels. Data provided by CORES.

The option which has recently been seen as the most promising, from the point of view of technology, is the electric engine. The reason for this choice, which is apparently supported by carmakers, is that electric motors are up to four times more efficient than combustion engines and that battery storage capacity has substantially increased through the use of lithium as raw material.

There are several technological options for a renewable-source platform to power electric vehicles.

Types of hybrid and fully-electric vehicles.



Hybrid electric vehicle (HEV). There is a wide range of hybrid options. These vehicles are powered by both electric and internal combustion motors. Some of the leading technologies in this area include: Full hybrid vehicles, in which traction is provided by an electric motor, gasoline engine, or both (Toyota, Lexus); Assist hybrid vehicles, in which the electric motor supports the gasoline engine in accelerating, angled slopes (climbing) and braking recovery (Honda); Regular hybrid vehicles, which use the electric motor for support. Hybrids include, in particular, the **Plug-in Hybrid Electric Vehicle (PHEV)**, which uses the electric motor to power the wheels while an auxiliary gasoline engine can recharge the battery (Chevrolet Volt) but can also be charged by plugging them to the mains. This option leads to better balance in consumption, emissions and autonomy (⇢500 km).

Battery electric vehicle (BEV). Operates on a single electric motor power by electricity stored in a battery charged through the mains (Mitsubishi I-MIEV). To date autonomy is limited (⇠150 km) which for the present seems to limit its use to urban areas.

The leading analyses currently underway regarding future transport modes indicate that road travel will, in the short term, aim at improving engine efficiency for gasoline-driven motors, while mid-term requirements will require an increased role of hybrid and battery-supported motors, so that the EU market could reach a balanced use between gasoline-driven engines and those based on electric alternatives for the period 2025-2030 (BCG, McKinsey&Company, 2009).

We should also mention that current applications of electric motors have not been analyzed in depth regarding their use either in road transport of goods or in airborne traffic. In both these cases the usual choice is either a combination of mode shifting to rail or improvements to the efficiency of existing motors. In the long run we would expect that road transport of goods will be combined with rail in an intermodal option, and that the alternative technology of choice will ultimately be either hybrid engines or hydrogen power.

4.3 Decisive support for the electric motor. What implications does this hold for Spain?

A transition to non-fossil fuel transport system may, for Spain, become an opportunity to pioneer the development of a system which allows integrating renewable-source electricity as the main resource to power future vehicles.

In this sense, Spain currently hosts a potential cluster incorporating research capabilities and industrial options in both renewables and the industrial sector which could, if implemented and fostered, lead towards developing the technological innovations necessary to promote the launching of renewables-based, electric-powered motor transport. Such developments could ultimately become the nucleus for industrial-technological growth within a global market.

Favouring movility based on renewable enrgies the following benefits could be obtained:

- Continuity and diversification in a growing renewable energy sector
- Modernizing and re-launching the automotive sector, in particular components, increasing its level of competitiveness
- Reducing greenhouse gas emissions, responsible for climate change and for pollution in urban areas which often results in breathing disorders
- Lowering requirements for imported fossil fuel used in transport
- Besides the above, electric vehicle batteries could be used to balance the contribution of renewable energy to the electric grid: drivers who do not use their vehicle during peak demand hours could sell energy stored in their batteries. In this way, renewable electricity stored during low demand periods could be available for maximum demand periods. [7]

A major feature of electric vehicles is the fact that they de not generate direct pollution, while their energy consumption is much lower than gasoline engines. Models now, or soon to be, on the market, have a power intake of 15-200Wh/km, so that travelling 100 km would require 15-20 kWh for a cost of 1.8 – 2.4 Euros. The average gasoline-powered vehicle would currently require 6.5 L of gas, for a cost of 5.85 Euros. On the other hand, it is also possible to reduce, to a greater or lesser extent, emissions of greenhouse gases and other pollutants by using electric vehicles, according to the means of generating electricity.[8]

On the other hand, there continue to be a number of issues to be resolved regarding the actual use of electric vehicles. The main concern is the high cost of batteries, their weight, and the vehicles' relatively limited distance autonomy. We should also bear in mind the fact that the existing electric grid in peninsular Spain could power a vehicle pool equivalent to approximately 25% of the current numbers without requiring building additional power plants if vehicles were charged during low-demand night-time hours (23:00 to 07:00), although with a computerized power charging management system it would probably be feasible to reach higher percentages. We should also consider that rarely more than 60% of the vehicle pool is in use at the same time.

7 The owner of an electric-powered vehicle this could provide an option to pay the vehicle's cost while not in use: charging low-cost power at night and then selling this power, at higher cost, during peak demand hours. There is no question that a "smart grid" allowing these transactions requires developing computer applications which are, at present, a major challenge, but which would at the same time facilitate citizen participation in the energy market as an active, and not only passive, agent.

8 CO_2 emissions from an electric car will perform according the means of generating the electric power stored in the battery. The existing mix in Spain's peninsular power grid would result, for a 100% electric car, emissions reaching approximately 55 grammes of CO_2 per km, while current average emissions in Spanish passenger cars is 158 grammes, so that electric vehicles would mean a reduction of 50%-60% CO_2/Km.

4.3.1 Need for a Vision towards 2050 in transport within a clear, ambitious objective

In order to resolve the double challenge of ensuring secure future transport without depending on oil and reducing the effects of the use of oil on the environment and society, it is necessary to define ambitious reduction targets in oil consumption while setting specific levels of future greenhouse gas emissions in the transport sector.

The global automotive market appears to lead towards progressive improvements in the efficiency of gasoline engines, due – to a great extent – to the increasing level of EU legislation, as well as to the gradual introduction of electric engines in the various hybrid and battery alternatives. While improving gasoline engines does not significantly promote the use of renewable energy sources (bio-fuels as an alternative are clearly limited and may have severe effects on the environment), the electric motor option leads to a full range of renewable energy sources: wind, solar, hydro, bio-mass, tidal/waves, geothermal, etc.

Spain would therefore be in a position to make use of domestic resources, rather than continue to act as passive buyer of new technology, if it decides to opt towards a clear, long-term policy leading to the use of electric engines and integrating such engines within a power grid in which renewable energy plays a growing role, from an estimated 10% in 2010 to some 100% in 2050.

In order to complete the transport sector transition towards an electric engine / renewables model our proposal is to establish a Road Map for Petroleum Substitution (2010-2050) with a clear forward vision for this sector which includes intermediate benchmark milestones (2020 and 2030) in order to monitor progress achieved towards meeting the established targets.

An initial, mid-term objective has been set for the EU's energy package, according to which 10% of energy used in the transport sector must, by 2020, be based on renewable sources, while new automobiles will be subject to emission limits below 95gr CO_2 / km.

By 2030, targets set for the transport sector must continue to aim at reducing demand, a modal change, and technological alternatives. Some of these objectives could be:

- Promote changes in transport of goods from road to rail traffic for distances above 200 km. A dense secondary distribution network based on rail hubs using mid-size vehicles powered by hybrid motors.
- Transport of goods towards North and Central Europe should make use of the so-called "highways of the sea".
- Traffic within urban areas should foster the use of public transport systems as well as full electric vehicles, basically in fleets such as the Postal system, taxis, public micro-buses, delivery vans, etc., with sanctions applied to the use of vehicles which waste fossil fuel as part of a tariff-based system on the basis of traffic volume.
- Personal intermediate-distance travel should basically depend on plug-in hybrid/gasoline engine vehicles powered by high-performance energy consumption and less weight, with consumption levels between 1.5 and 1.3 litres of fossil fuel per 100 km.

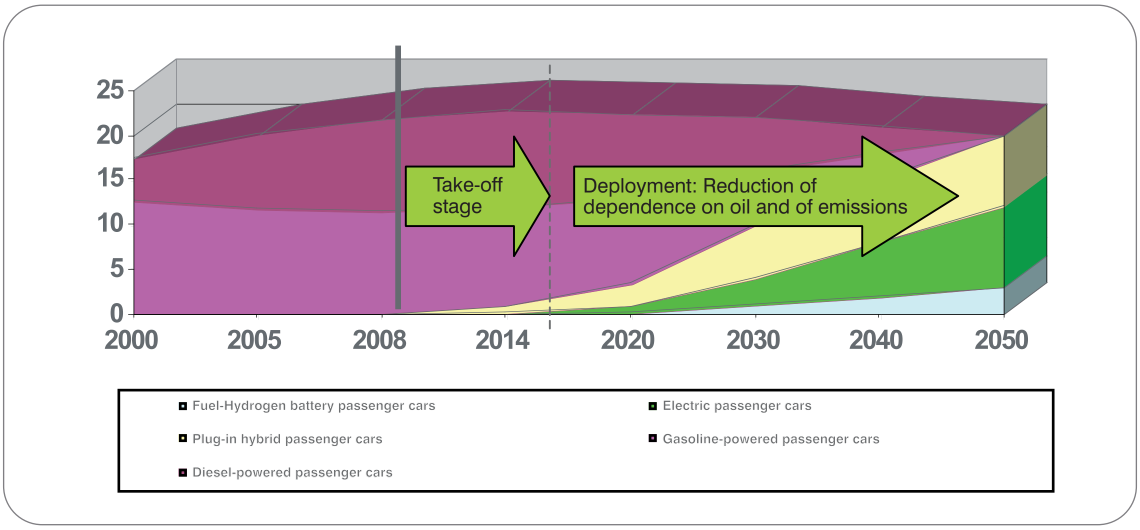
Within the terms of this paper Spain's priority targets for 2050 should be similar to those currently under discussion in other EU member countries:[9]

9 National long-term transport plans are currently under development in both France and Germany in which the traffic model based on electric motors has become the core concept for future transport, particularly in the automotive sector. Other countries such as Israel, Portugal, Ireland and Denmark have made public their interest in this technological alternative to the gasoline engine. The Norwegian Parliament is debating the possibility of passing a law prohibiting the sale of cars which are not, at least, hybrid as of 2010.

1. Reduce consumption of petroleum by-products used in transport by 95% (in 2008 dependence was 97% with a cost for Spain's economy for total imports of oil and oil by-products amounting to 44,500 million Euros, equivalent to 4% of GDP, compared to 1%-2% for most EU-15 member countries).
2. Reduce CO2 emissions in the transport sector by 90%. This would require that practically all vehicles in Spain would not cause CO2 emisions, since the remaining 10% would result from air traffic energy consumption.
3. Reach 80% of the transport sector energy consumption in renewable-based electricity, 10% 2nd-generation sustainable bio-fuel and 10% fossil fuel for "niche" applications such as aircraft.
4. Establish and disseminate the concept of "pay per distance", and not on the basis of energy, through a computerised management system which charges according to distance travelled and demand for transport at any given time. This traffic model is directly coupled with transport based on electricity.

As Chart 4.5 shows, a sustained, early and gradual approach to electricity-based mobility could lead to a vehicle pool without fossil fuel needs by 2050, in which the main energy sources would be renewable electric power, 2nd-generation sustainable bio-fuel, and possibly hydrogen.

Chart 4.5 Spain's passenger vehicle pool and potential scenario for 2050 including electric power (million).



The majority of an approximate total 20 million passenger cars forecasted to be on the roads in 2050, some 45%-60%, could be full electric, with 30%-50% plug-in hybrids running on a minimum contribution of sustainable bio-fuel and 0%-15% hydrogen powered.

A passenger car pool in 2050 responding to the above figures would lead to the almost complete replacement of oil by domestic renewable energy.

Table 4.1 shows several milestones which could help reaching this target by 2050:

Table 4.1 Possible Road Map for Petroleum Substitution milestones (2010-2050)

Targets	Measures	Inversiones
1 Take-off stage 2010-2015	Develop Take-off Plan Creation of Technological cluster Creation of Special Fund for Sustainability in Transport (FEST) Regulation promoting the sale of electric-powered vehicles	Public investment in R+D+I Purchase of hybrid vehicles for public and private fleets Basic power-charging network in cities (Administrations and utilities).
2 Implementation stage 2016-2030	Develop fully commercial vehicles (2nd generation) Develop a vehicle batteries/power grid interface with higher % of renewables Implementation of a computerised traffic-management system Regulations prohibiting the sale of vehicles powered exclusively by gasoline.	Full development of power-charging networks (Utilities) Public and private R+D+i investments Public support measures for deployment of traffic-management companies.
3. Final conversion stage 2030 - 2050	Progressive replacement of improved gasoline engines by electric and sustainable hydrogen.	Private investments in R+D+i Leading role of private sector.

Financing is a key element in ensuring the possibility of reaching the targets set in the Road Map. Our proposal to this end is to create a Special Fund for Sustainability on Transport (FEST) funded through contributions from both the public and the private sectors. This Fund would be responsible for initial financing of the necessary technological development as well as for the early marketing of electric vehicles and developing the basic power-charging network. In the mid- and long term the private sector, particularly electric utilities, should take on increased investment.

4.4 Conclusions

The purpose of this paper is to launch an exchange of ideas concerning the vision described in the text towards the year 2050 for a transport system leading to increased prosperity for Spain, which will create wealth, improve the quality of life of its citizens, respec the environment and uphold the country's long-term sustainability. The project has a 40-year life span, but it is necessary to take action immediately if the vision is to become a reality within the time frame described:

- The global oil market may be in severe imbalance on the mid-term if it is not capable of satisfying a growing demand for fossil fuel, particularly in emerging economies. At the same time, climate change is daily increasing the urgency to stop using fossil fuel so as to avoid greenhouse gas emissions.
- The future of transport in Spain requires a change in paradigm, leaving behind the model in which more available transport equals increased creation of wealth. We must disassociate growth in social welfare from the need for transport.
- This, in turn, requires the implementation of policies which lead to decreased demand for transport while bringing about alternative modes of traffic for people and goods which reduce the effects of transport on the environment and human health.
- These alternatives must provide a leading role for:
  - In the short term: reductions in energy consumption, particularly road traffic, by means of demand-lowering measures, promotion of public transport, modal changes in the transport of goods, and introduction of alternative technologies in the automotive sector.
  - In the long term: urban and land planning policies leading to a reduced need for transport, gradual implementation of technologies which do not require consumption of fossil fuel, such as electric motors, which would allow basing transport in Spain on domestic renewable energy.
- Spain is in a position in which it can make this challenge become an opportunity for progress by opting for a combination of electric motor / renewable energy, which – if properly implemented – could become an economic nucleus of international relevance.
- We must bring about a Vision towards 2050 involving a Road Map with clear, ambitious goals, wich defines the details of how to reach the changes necessary in the transport sector towards economic, social, and environmental sustainability. Financing this objective would require creating a Fund, financed by the Administration and the private sector, responsible for promoting the necessary research, development and actions required to make real the objectives of this Vision.

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References

Calidad del Aire en las ciudades: Clave de sostenibilidad urbana. Observatorio de la Sostenibilidad en España, 2007.

Costes Externos del Transporte. Estudio de Actualización. IWW, Universitaet Karlsruhe – INFRAS, 2004.

Développer les éco-industries en France. The Boston Consulting Group, 2008.

Disociar crecimiento económico y demanda de transporte. Caso de Estudio de España. Proyecto OCDE. Ministerio de Medio Ambiente, 2005.

On the Road in 2035: Reducing Transport's Petroleum Consumption and GHG Emissions. MIT, 2008.

Plan Estratégico de Infraestructuras y Transporte (PEIT). Ministerio de Fomento, 2005.

Perspectivas sobre tecnología energética 2008. Agencia Internacional de la Energía, 2008.

Spain (2005 Review): Energy policies of IEA countries. Agencia Internacional de la Energía, 2005.

Sostenibilidad en España 2006. Observatorio de la Sostenibilidad en España.

Sostenibilidad en España 2007. Observatorio de la Sostenibilidad en España.

The Future of Transport. Focus Groups Report (informe para la CE), 2009.

The comeback of the electric car? The Boston Consulting Group, 2009.

Transport 2050: The route to sustainable wealth creation. The Royal Academy of Engineering, 2005.

Roads toward a low-carbon future: Reducing CO2 emissions from passenger vehicles in the global transport system. McKinsey&Company, 2009.

Toward a sustainable energy future. Agencia Internacional de la Energía, 2001.

Transport at a crossroads. TERM 2008. Informe Agencia Europea del Medioambiente Nº3/2009.

Urban sprawl in Europe – The ignored challenge. Informe N10/2006, Agencia Europea del Medioambiente, 2006.

Vision 2050: An integrated national transport system. Federal Transport Advisory Group (Gob. EEUU), 2001.

World Energy Outlook 2008. Agencia Internacional de la Energía, 2008.

5 Economic implications of the new model: more and improved jobs and international markets [1]

5.1 Introduction

Historically speaking, economic growth and population increase have been accompanied by rises in energy consumption. The energy crisis of the 1970s and the socio-economic consequences left in its wake in terms of increased inflation, growing trade deficit and higher unemployment rates, created the conditions for the first energy efficiency and savings plans. The environmental rationale behind the development of renewable energy sources took a little longer to gain its place in the political arena. It was not until 1986 that Spain passed its first Plan for the Promotion of Renewable Energy Sources. (Blanco Silva, 2004)

Since that time energy policies have come a long way. In 2009 Spain leads Europe in terms of power generated using renewable energy sources. At the end of April the IDAE (Institute for Energy Diversification and Savings) announced that Spain was the leading country in solar thermoelectric power in Europe in installed capacity, second in wind and solar photovoltaic power and ranked third in mini-hydro and bio-ethanol production. What is more, at international level, Spain's wind power represented last year, 14% of installed capacity and in 2005 we were already the World's second largest producer of wind power. Likewise, Spain's production of solar photovoltaic power ranks very high at 7% of generator production. Our leadership extends to the solar thermoelectric power, a field in which we have outstanding capacity in innovation and technological development.[2] Stable and sustained public support of renewable energies, as well as a firm long term commitment from the private sector to these technologies, is undoubtedly what will enable us to maintain this leadership.

The analysis herein is based on the assumption that it is technically practicable to cover Spain's electricity demands by 2050 using renewable energy sources, as proposed already in chapter 3. This is good news if the objective is to reduce energy dependency, estimated to be 78%[3] in 2002.[4] However, if in addition we wish to fulfil our international obligations in regard to climate change and reduce greenhouse gas emissions (GHGE), the technical viability of renewable energies is further incentive towards achieving a low carbon future.

The fact that the renewable energy sector directly employs 84.667 people and similar numbers indirectly[5] is an additional encouragement to continue to develop a sector which offers a substantial degree of job security in comparative terms. This sector also requires a higher skilled workforce compared with other energy sectors. Current economic circumstances are driving public administration towards renewable energies and as we will see in this chapter, these are likely to generate more employment throughout the useful life of the plants than conventional energy sources.

1 This chapter is authored by Lara Lázaro Touza and Rolando Fuentes Bracamontes, Fellows of London School of Economics, Department of Geography and Environment.

2 For a more detailed explanation please refer to: http://www.idae.es/index.php/mod.noticias/mem.detalle/id.70/relcategoria.121/relmenu.75

3 http://www.energiasrenovables.ciemat.es/especiales/energia/espana.htm#1

4 It should be noted that energy dependency per se is not harmful given that for reasons of efficiency and availability of fuel reserves, it may be convenient/necessary to look to other countries to satisfy our domestic demands. However, the instability of these countries and the volatility of prices are often good reasons to prefer to opt for a higher degree of energy independence.

5 Please note that the data on employment furnished by IDAE differ from those provided by the Spanish Trade Union Institute for Labor, Environment and Health (Instituto Sindical de Trabajo, Ambiente y Salud) ISTAS (2008)

In the second section of this chapter we shall examine the effect of electric power generation using 100% renewable energy mix on employment. In section three we shall look at the costs this energy mix entails. And, the fourth section will set out to present the strategic opportunities that renewable energies offer Spain. Section five closes the chapter highlighting the main conclusions of this study.[6] Long term visions and forecasts tend to be uncertain and very quickly become obsolete so we need to keep in mind that the data herein presented are merely illustrative of potential scenarios. Despite the uncertainty inherent to the formulation of these scenarios a number of authors have pointed to the need for governments effectively plan their energy sector, and that these outcomes should not be taken as forecasts but as a means to informed decision making in the present to ensure the future we desire (Giddens, 2009).

5.2 Employment: potential scenario for a 100% renewable future

This section will set out the estimations for direct employment generated by the renewable energy sources sector for 2007 and 2050.[7] Additionally we submit figures for indirect and direct employment in the electrical power sector for 2050. Our calculations are based on installed capacity scenarios for electrical power generation in Spain and the assumptions set out in chapter 3.

For the purpose of formulating data on potential employment in the Renewable Energy Sector (RES) in Spain in 2050, we have taken the studies conducted by Kammen et al., (2006) and Fankhauser et al., (2009), Sánchez López (2006) and ISTAS (2008) which provide a theoretical base for one of the possible future scenarios, in 2050 all electrical power generation will be based 100% on renewable energy.

To facilitate a comparison between the two snap shots these data present, we shall first examine the data for 2007 followed by those for 2050.

Source of Electrical Power Generation	Installed Capacity (MW)	Jobs per MW installed	Total direct Jobs
Hydraulic < 10MW	1852	4.97	9204
Biomass	396	13.55	5366
Wind	15090	2.52	38027
Solar Photovoltaic	638	44.98	28697
Biogas	166	17.40	2888
Solar thermoelectric	11	44.00	484
Total Jobs			**84667**

Table 5.2.1. Direct Jobs 2007: Electrical Power
Source: Own formulation compiled from data pertaining to installed capacity furnished by the Ministry of Industry (MITYC, 2007) and ISTAS (2008)

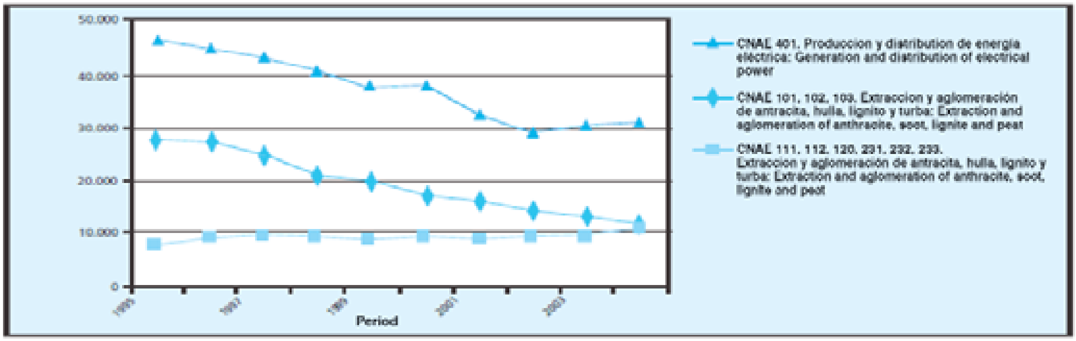
6 The appendix shows the estimates for a 100% nuclear future.

7 According to the definitions used by Sánchez López (2006), direct employment includes design, R&D, construction, assembly, installation, operation and maintenance of the plant. Indirect employment encompasses deliverables from external companies.

According to the figures on table 5.2.1 the sector responsible for the creation of the highest number jobs in renewable energy-based electrical power generation in 2004, was wind followed by solar photovoltaic power. The figures may vary slightly depending on the ratio used of jobs to MW installed. This means that we should focus not so much on the figures but on the fact that renewable energies are a source of greater job creation than conventional energy sources, Sanchez López (2006) and ISTAS (2008).

By way of example, we can compare the previous figures shown on table 5.2.1 (or more conservative data furnished by IDAE) with the generation of direct employment from other energy sectors, such as nuclear power which in 2005 employed some 4.123 people of which 52.8% are on the nuclear power plant payroll. During periods when the nuclear power plants are being recharged, this staff increases to 10.930 of which 20% is on the payroll (CC.OO., 2006). According to the Nuclear Forum (Foro Nuclear), the number of workers (under contract and on the payroll) was 8.152 in 2007 (Foro Nuclear, 2008).

Craph 5.2.1. Jobs in the conventional energies sector in Spain 1995-2005



Source: Sánchez López (2006: 21). Form data provided by INE (National Institute for Statistics) (2006)

Moreover, the ratio of jobs created to installed capacity in MW of renewable energy is higher in comparison with conventional sources of power generation (see for example Fankhauser et al., 2009; Kammen et al., 2006 or Sánchez López, 2006). Thus, the number of jobs created throughout the useful lifetime of the plant according to energy source is shown on the table below:

Table 5.2.2. Average Employment throughout the useful life of the plant (jobs/MW)

	Construction, Manufacturing & Installation	Operation, Maintenance and Fuel processing	Total jobs
Solar Photovoltaic	5.76 – 6.21	1.20 – 4.80	7.41 – 10.56
Wind	0.43 – 2.51	0.27	0.71 – 2.79
Biomass	0.4	0.38 – 2.44	0.78 – 2.84
Coal	0.27	0.74	1.01
Gas	0.25	0.7	0.95

Source: Translated from Fankhauser (2009: 423 .[8]

That is to say, that in terms of construction, manufacture and installation, renewable energy sources are more manpower intensive per MW installed than traditional energy sources. The operation and maintenance of solar/photovoltaic technology continues to be more manpower intensive than coal or gas. For the remaining technologies the number of jobs per MW installed in operation and maintenance may be lower than coal and gas. Regarding total number of direct jobs (last column of table 5.2.2) if we look at the mid-point of the interval RES are still more manpower intensive than conventional sources. Generally speaking, the studies analyzed all coincide that renewable energies are more manpower intensive than conventional power sources. This is partly explained by the fact that some of these technologies are not yet cost-effective and in part due to the nature of some of these renewable sources (for example biomass) which means in the future they will still be more labor intensive than the conventional energy sources. Also, the useful life of the RES fuelled power plants on average is shorter than those of conventionally fuelled plants which again require a larger work-force to replace the facilities.

These ratios will vary as the technologies mature so, although for the purpose of this analysis we are working on the basis of the figures presented by Fankhauser et al., (2009) for 2050 and those presented by ISTAS for 2020, we do acknowledge that these are just ball park figures as we do not have data pertaining to the trends in employment for the different technological options for such an extended period.

As we have seen, the shift over to 100% renewable-based electrical power generation will lead to both job creation and job losses in sectors such as nuclear power, which will gradually peter out or disappear. The final balance of employment in the power generation sector will depend on the importance of these industries and how labor-intensive they are, Fankhauser et al., (2009). In fact, the effect of energy transition on employment across the entire economy will be dependent on many different factors. One such factor is the price of electricity in 2050 for power-intensive industries such as the cement industry or aluminium. The data presented herein take into account those factors and show the great employment generation potential of the model proposed in this report.

Assuming, that technically speaking, the proposed power generation transition were feasible and job creation figures per MW installed were still as presented on table 5.2.2., and, accepting the ISTAS employment scenarios for RES in 2020, direct employment generated in 2050 could well be as follows:

8 As shown, the employment calculations presented in the ISTAS report (2008) and the figures presented by Fankhauser et al. (2009) do not coincide. Had the employment figure for 2007 been calculated using the data on table 5.2.2, the figure would be markedly lower. It is also important to highlight that (as the authors cited have mentioned) authors such as Pfaffenberger et al., (2003), (2006) and Schulz et al., (2004) posit that in the next 10 to 15 years these increases will not be sustained.

Table 5.2.3 Direct jobs 2050: High demand scenario

Technologies	Installed capacity (MW)	Ratio jobs/MW		Jobs created		
		C, M, I	O&M	C, M, I	O &M	Direct jobs
Solar photovoltaic	23.000	6.21	1.2	142.830	27.600	170.430
Wind	50.000	0.43	0.27	21.500	13.500	35.000
Solar thermal	47.000	6.58	0.42	309.260	19.740	329.000
Biomass	20.000	0.4	0.38	8.000	7.600	15.600
Geotherma l	500	0.27	0.74	135	370	505
Wave	2.000	0.43	0.27	860	540	1.400
Mini-hydro	2.230	3.73	0.24	8.318	535	8.853
TOTAL						**560.788**

Table 5.2.4 Direct jobs 2050: Medium demand scenario

Technologies	Installed Capacity (MW)	Ratio jobs/MW		Jobs created		
		C, M, I	O&M	C, M, I	O &M	Direct jobs
Solar Photovoltaic	10.000	6.21	1.2	62.100	12.000	74.100
Wind	37.000	0.43	0.27	15.910	9.990	25.900
Solar thermal	31.000	6.58	0.42	203.980	13.020	217.000
Biomass	7.000	0.4	0.38	2.800	2.660	5.460
Geothermal	300	0.27	0.74	81	222	303
Wave	1.000	0.43	0.27	430	270	700
Mini-hydro	2.230	3.73	0.24	8.318	535	8.853
TOTAL						**332.316**

Table 5.2.5 Direct jobs 2050: Low demand scenario

Technologies	Installed capacity	Ratio jobs/MW		Jobs created		
		C, M, I	O&M	C, M, I	O &M	Directs jobs
Solar Photovoltaic	6.000	6.21	1.2	37.260	7.200	44.460
Wind	28.000	0.43	0.27	12.040	7.560	19.600
Solar thermal	9.000	6.58	0.42	59.220	3.780	63.000
Biomass	2.000	0.4	0.38	800	760	1.560
Geothermal	300	0.27	0.74	81	222	303
Wave	300	0.43	0.27	129	81	210
Mini-hydro	2.230	3.73	0.24	8.318	535	8.853
TOTAL						**137.986**

Source: Own data formulated based upon the installed capacity figures from García Casals (chapter 3 of this report) and more conservative figures from table 5.2.2, the MW installed furnished by ISTAS (2008) for the calculations for 2020 in Solar thermal and mini-hydro and assuming that the ratios for geothermal power generation are equivalent to those of a coal-powered plant. For wave energy, we have assumed that the ratios of jobs/MW installed are equivalent to those for wave power. The acronyms C, M, I stand for construction, manufacture and installation, while O and M stand for plant operation and maintenance as well as the processing of fuel. The total number of direct jobs created on this table, has been rounded off.

The number of direct jobs created in electrical power generation [9] could then oscillate between 137.986 and 560.788. If we also include indirect jobs using a ratio of indirect job creation of 1.2 indirect jobs created for every direct job (Nieto Sainz, 2008: 10), and assuming that this ratio is sustained in the long term, then the number of indirect jobs creates in a low demand for electrical energy scenario would be 154.544, 372.194 for a medium level electrical power demand scenario and 628.083 for the high electrical power demand scenario.

In summary, the total number of (direct and indirect) jobs created in the Spanish electrical power generation sector, in the aforementioned scenarios and assumptions may be in the range of 292.531 to 1.188.871. Given that these data are incomplete, a more global picture of the new renewable energy based model could be derived from the use of input-output tables which show the effects of the shift in power generation on the entire Spanish economy (Fankhauser et al., 2009).

Although we still do not have specific data from what could amount to four decades of research, development and innovation, we can expect quantitative and qualitative changes in RES. This effect will be further magnified by the governments support policies addressed to this sector. This is all part of a concerted effort to combat climate change involving all sectors and social stakeholders. The opportunities of leadership and strategic positioning Spain has been afforded thus far should encourage the Government to continue to lend its support to renewable energies in the future without overlooking the opportunity cost this implies.

5.3 The cost of energy transitioning to a 100% renewable future

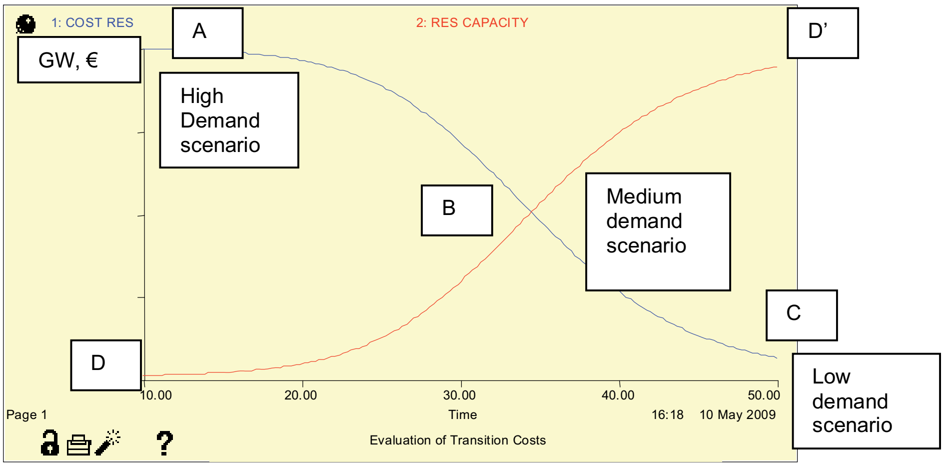
This next section shall focus on an analysis of the energy sector transition costs for an industry looking to base 100% of its power generation on renewable energy sources. Transition costs are defined to be the cost of the necessary installed capacity required to reach the 100% renewable energies target. So, we focus not only on the capital cost and the necessary installed capacity to cover the program. This chapter should not be construed as a cost/benefit analysis of the program. We are not analyzing all the benefits not the operation of the program. So, in this section we shall only concern ourselves with the calculation of how much it would cost to set up the aforementioned scenarios.

Ideally, the cost calculation which we refer to as transition should be formulated by calculating the net present value of the cost of GW installed in each period. The capital cost however, is not a static variable. We expect this cost to shrink – as is the case when new technology is initially adopted and then becomes widespread; this cost reduction should be more pronounced in the initial periods and will then settle down towards the end of the period in question following an inverted "s" shaped curve. The same applies for construction and installation of capacity using renewable energy sources. We would expect to see this happen gradually over a 40 year period in a manner analogous to an "s" curve: proportionally fewer GW installed while the existing plants are still productive and then a sharp increase once these are taken out of commission and then settling down once again towards the end of the period. From a logistics standpoint it would prove too complicated to install full capacity in the final years of the period.

However, there is no certainty regards how any of these variables will perform in the future, capital cost and new installed capacity. In the face of such uncertainty in this chapter we present three incomplete scenarios which together could provide decision-makers with a framework to base their decisions on. These three scenarios are "snap-shots" of the transition costs at three different stages in the process. The problem is illustrated in the graph below.

9 This analysis is limited to the technologies presented on tables 5.2.3, 5.2.4 y 5.2.5 as the data for jobs created per MW installed capacity refer only to these technologies.

Graph 5.3.1 Expected evolution of Costs and Installed capacity of RES



A= Initial capital cost of renewable energy technologies (2010)
B= Capital cost of renewable energy technologies in the intermediate phase (2025)
C= Capital cost of renewable energy technologies at the end of the period (2050)
D= Installed capacity of renewable energy at the outset (2010)
D'= Installed capacity of renewable energy at the end of the period (2050)

The high demand scenario has been calculated based on the assumption that the transition shall occur over night in the present and therefore at current cost. The advantage of this scenario is the certainty afforded by the use of real cost data. The downside is that this is an excessively conservative estimate which does not account for a probable reduction in the cost of renewable energy technologies, as is the case when new technologies are introduced and their use becomes widespread. The intermediate scenario takes the predicted costs for 2025. The advantage in this case is that the predicted cost is more feasible as it is closer to the present cost. And also, as we mentioned earlier, it is very likely that the construction and installation of these technologies will be within this price range. This means that the intermediate scenario is the one we recommend. The low demand scenario is based on probable cost of renewable energy technologies projected for 2050 assuming that the implementation and dissemination of these technologies has been successful. This is one possibility, but not the only one. Just as in the high demand scenario we have taken as a given that the construction and installation has happened over night, underestimating the cost of depreciation of the new plants as well as the logistic problems posed by such an ambitious project.

Chapter three presents different demand scenarios. Each transition cost scenario is presented in certain ranges so as to encompass varying demands. We distinguish different types of cost, financial and economic. The financial cost refers to the amount of money spent to "purchase" the proposed capacity. The economic cost is considered to be the "savings" in future investments not undertaken in conventional technologies.[10] Based on this assumption, the transition cost towards 100% renewable energy source-based power generation have been calculated using the figures set out in the table below:

10 To illustrate and clarify this point, for example we consider that these technologies are sold or ownership is transferred at market price.

Table 5.3.1 Transition costs according to varying technology costs

Transition cost (Million Euro)	Minimum	Maximum	Average
High (current costs)			
Financial Cost	123.903	571.183	347.543
Economic Cost	69.305	516.585	292.945
Medium (Costs 2025)			
Financial Cost	5.400	101.011	53.206
Economic Cost	- 15.752	79.859	32.054
Low (Costs 2050)			
Financial cost	38.725	166.077	102.401
Economic Cost	2.201	129.553	65.877

Source: Own calculations based on the capacity proposal presented in chapter 3, and capital cost figures presented by García Casals (2005) and Islas et al., (2003)

Another important outcome is that with the proposed capacity mix, and assuming that the long term price[11] is equal to the long term marginal cost, the price of electricity shall be dictated by the most costly technology which services the final point of demand. According to García Casals (2005), this will be photovoltaic power. The "growth rate" column illustrates the percentage change in current and future costs to clarify the variation we factor in for technology.

Table 5.3.2 Current and future operation and maintenance costs

Technology	Operation and Maintenance costs c€/KWh Current	Operation and Maintenance costs c€/KWh 2050	Growth rate
Photovoltaic	3.81	3.17	-17%
Gas	0.35	3.35	857%
Wave	14.41	1.73	-88%
Hydro	2.42	1.74	-28%
Geotherma	4.00	1.50	-63%
Nuclear	0.94	8.94	851%
Wind	0.88	0.58	-34%
Biomass	0.80	0.42	-48%
Solar thermal	2.80	0.40	-86%

Source: García Casals (2005: 20)

11 We are referring to the average price, as due to the nature of the electricity markets, where power cannot be stacked, prices tend to be highly volatile with large differences between peak demand and trough and base levels. Likewise we are assuming that the capacity proposed in chapter three allows for a sufficient reserve margin so that scarcity of capital would not be a factor in the price estimation and that this be based exclusively on generation costs alone.

5.3.1 The estimation process

The main assumption on which transition is calculated is that this occurs over night. That is to say, we have not included the installation or construction of renewable energy sources capacity time variable. Likewise we are assuming that the disappearance of nuclear energy and fossil fuels will also occur from one day to the next. This would be akin to saying that the installed capacity is sold or ownership is transferred so avoiding the costs of keeping the former technologies alive.

We have estimated the investments which would be required by the end of the period, in 2050, for the capacity mix to be the one presented in chapter 3, as high, medium and low demand scenarios. This way we leave aside construction time and depreciation of capacity, which would have to be added each year to be at target installed capacity in 2050.[12]

The table below is a breakdown of the calculation based on graph 5.3.1. It also shows arguments in pro and contra, as well as the balance of each scenario.

Table 5.3.3 Current and future generation costs

Scenario	Calculation	Over-estimation	Under-estimation	Balance
High	A x (D'-D)	Not considering a an expected reduction in technology cost due to technological advances and economies of scale	Not considering construction time, depreciation of new capacity and other necessary parallel investments	Certainty, but must be taken as the transition cost ceiling
Medium	B x (D'-D)		Not considering future depreciation nor the effect of a higher demand for RES on capital costs	Costs are future but less uncertain. Potentially most investment occurs at this stage
Low	C x (D'-D)		Proportionally lower capacity built at these prices	Acknowledges technological advance in renewable energies

We consider that the cost of overnight switch to a model of 100% renewable energy source-based generation is only capital cost in installation. We have excluded additional costs such as distribution and construction of plants. Table 5.3.4 presents the baseline situation and future scenarios for 2050.

12 So, we could be underestimating capacity price as we expect the related capital costs to decrease with more widespread use, economies of scale and new technologies

Table 5.3.4 A comparison of the present and future generation capacity mix

Technology	Current composition GW	Composition 2050 GW		
		High	Medium	Low
Coal	14.5	0	0	0
Oil	10.1	0	0	0
Gas	24.7	0	0	0
Nuclear	7.4	0	0	0
Hydro **	18.1	24.8	24.3	24
Wind	16.7	50	37	28
Photovoltaic	0.2	23	10	6
Solar thermal*	0.2	47	31	9
Biomass*	0.2	20	7	2
Geothermal*	0.2	0.5	0.3	0.3
Wave *	0.2	2	1	0.3
		0	0	0
Total	92.2	147.3	103.6	67.6

* These renewable energy technologies are classified under "Other technologies"
And amount to 1 GW.
We assume that the participation is homogeneous for the purpose of this comparison.
** Includes all categories of hydroelectric plants

Source: Own calculations based upon the scenarios proposed in chapter 3

In order to achieve the mix proposed in the different scenarios nuclear energy and other fossil fuel dependent technologies must be eliminated. This involves not only adding renewable-based capacity to the generation facilities but also replacing existing technology.

Table 5.3.5 Installation required expressed in GW to achieve the proposed mix

Technology	Investment GW		
	High	Medium	Low
Coal	-14.5	-14.5	-14.5
Oil	-10.1	-10.1	-10.1
Gas	-24.7	-24.7	-24.7
Nuclear	-7.4	-7.4	-7.4
Hydro	6.7	6.2	5.9
Wind	33.3	20.3	11.3
Photovoltaic	22.8	9.8	5.8
Solar thermal	46.8	30.8	8.8
Biomass	19.8	6.8	1.8
Geothermal	0.3	0.1	0.1
Wave	1.8	0.8	0.1
Total	55.1	11.4	- 24.6

Source: Own calculation based on the scenarios proposed in chapter 3

Based upon the data proposed by García Casals (2005) and de Islas et al., (2003) we have taken technology capital costs to be those found in the table below. Should there be different categories of the same family of technology (for example wind power generation in flat, mountainous terrain or off-shore) we would take the lowest value when referring to renewable energy sources and the highest value if referring to conventional technology.

Table 5.3.6 Capital Costs of transition

Technology	Capital cost in Millions of euro/GW Current	Capital Cost in Millions of euro/GW 2025	Capital Cost in million of euro/GW 2050
Coal	1.342	930	ND
Oil	595	595	ND
Gas	520	328	520
Nuclear	2.200	1.623	3.200
Hydro	2.500	1.342	1.800
Wind	880	518	481
Photovoltaic	8.114	1.151	962
Solar thermal	4.439	1.855	1.373
Biomass	6.223	1.123	2.503
Geothermal	5.831	916	1.729
Wave	3.600	ND	825

Source: Current cost and costs for 2050 we both taken from García Casals (2005) and costs in 2025 were taken from Islas et al. (2003). ND: no data available.

The following tables present a breakdown of the investment costs required according to the three scenarios: High, medium and low, and the current transition costs out to 2025 and 2050.

Table 5.3.7 Cost of investment in transition at current capital costs

Technology	Capital cost in Millions of euro/GW current	Amount of investment in millions of euro		
		High	Medium	Low
Coal	1.342	- 19.463	- 19.463	- 19.463
Oil	595	- 6.011	- 6.011	- 6.011
Gas	520	- 12.844	- 12.844	- 12.844
Nuclear	2.200	- 16.280	- 16.280	- 16.280
Hydro	2.500	16.750	15.500	14.750
Wind	880	29.304	17.864	9.944
Photovoltaic	8.114	185.270	79.788	47.332
Solar thermal	4.439	207.893	136.869	39.211
Biomass	6.223	123.423	42.524	11.409
Geotherma	5.831	1.944	777	777
Wave	3.600	6.600	3.000	480
Total financial cost		571.183	296.322	123.903
Economic Cost		516.585	241.724	69.305

Source: Formulated on the basis of data from García Casals (2005)

Table 5.3.8 Cost of investment in transition at 2025 prices

Technology	Capital cost Millions of euro/GW 2025	Amount of investment in euro millions of		
		High	Medium	Low
Gas	328	- 4.760	- 4.760	- 4.760
Nuclear	1.623	- 16.392	- 16.392	- 16.392
Hydro	1.342	- 33.154	- 33.154	- 33.154
Wind	518	- 3.831	- 3.831	- 3.831
Photovoltaic	1.151	7.708	7.133	6.788
Solar thermal	1.855	61.758	37.649	20.957
Biomass	1.123	25.639	11.042	6.550
Geothermal	916	42.890	28.237	8.090
Wave	ND			
Total financial cost		101.011	47.076	5.400
Economic cost		79.859	25.924	- 15.752

Source: Formulated with data from Islas et al. (2003)
Note: The financial and Economic costs do not include the Wave energy as we have found no available data. Thus both the financial and Economic costs are underestimated.

Table 5.3.9 Cost of investment in transition at 2050 prices

Technology	Capital cost in Millions of euro/GW 2050	Amount of investment in millions of euro		
		High	Medium	Low
Gas	520	- 12.844	- 12.844	- 12.844
Nuclear	3.200	- 23.680	- 23.680	- 23.680
Hydro	1.800	12.060	11.160	10.620
Wind	481	16.017	9.764	5.435
Photovoltaic	962	21.966	9.460	5.612
Solar thermal	1.373	64.302	42.334	12.128
Biomass	2.503	49.643	17.104	4.589
Geothermal	1.729	576	231	231
Wave	825	1.513	688	110
Total financial cost		166.077	90.740	38.725
Economic cost		129.553	54.216	2.201

Source: Formulated using data from García Casals (2005)

So, the financial cost of transition would range from (on average) 102.401 million euro to 347.543 million euro. The economic cost for its part would range between 65.877 million euro and 292.945 million as shown on table 5.3.1.

5.4 Strategic oportunities on international markets

One of the main potential benefits of supporting an ambitious program to transform the energy sector into a renewable energy source-based power generation industry is to gain a competitive advantage over other competing countries in what looks to be a large, attractive market. If Spain can materialize this transformation it would certainly have an advantage over its competitors. In order to calculate the potential benefits for Spain we would need to know the magnitude of this potential market and the stake Spain would hold in it. In this next section we shall focus our attention on the former: the potential dimensions of the renewable energies market in the future. It is complicated to venture a forecast of the stake Spain might have in such a market as, just as in any new market, that stake would depend not only on steps taken by Spain but also the response from other large competitors – currently, Germany, Denmark and, it is highly that other countries will not want to sit on the sidelines, looking on – United States, Great Britain, France, China and India

According to our calculations, however, the future magnitude of the renewable energies market in itself merits some strategic decisions in this direction. By virtue of the Greenpeace report "Energy Revolution" which posits two energy scenarios,[13] we have estimated the possible increase in renewable energy source-based installed capacity based upon the predicted installation costs in 2050[14]. We present herein two scenarios: the first follows current trends (scenario ref), and the second takes into account the current global drive towards the use of renewable technologies (scenario R).

The following table presents the global market for renewable energy technologies based the above assumptions:

Table 5.4.1 Size of the potential global renewables technologies market

Global Installed capacity GW	Year				Potential Market M€ Reference scenario	Potential Market (M€) Scenario-R
	2010	2050	2010	2050		
Technology	Reference Scenario		Scenario -R			
Hydro	989	1711	978	1565	1.299.600	1.056,600
Win	124	593	164	2733	225.589	1.235.689
PV plants	10	153	21	2911	137.566	2.780.180
Solar thermal	2	17	5	801	20.595	1.092.908
Biomass	70	203	95	620	332.899	1.314.075
Geothermal	11	36	14	276	43.225	452.998
Wave	0	9	1	194	7.425	159.225
TOTAL					**2.066.899**	**8.091.675**

Source: Own calculations based on data from Greenpeace and García Casals (2005) installation costs for 2050 (see table 5.3.6)

To put all this information into perspective, the following tables illustrate the size of the potential market in several areas where Spain has a presence. The main areas are Europe, Latin America and potentially the US and Canada. We also illustrate the potential market for renewable energy sources in Africa. Africa could be strategic to the development of these technologies especially solar thermal energy.

13 First the energy scenarios calculated by the International Energy Agency 2030 published in the World Energy Outlook (WEO, 2007) and which Greenpeace extrapolate to 2050 ('ref scenario) and subsequently the energy scenarios Greenpeace proposes as the target to be achieved by 2050 if we wish to reduce Green House Gas emissions to a level 50% below those of 1990 (Scenario R).

14 Please refer to the previous section for a discussion on the potential costs in 2050. The data we have used are the same as in the previous section.

Table 5.4.2 Size of the potential renewable energies market in Europe

Installed capacity Europe OECD GW	Year				Potential Market (M€) Reference scenario	Potential Market (M€) Scenario-R
	2010	2050	2010	2050		
Technology	Reference scenario		Scenario -R			
Hydro	187	227	174	182	72.000	14.400
Win	64	207	87	333	68.783	118.326
PV plants	5	47	10	357	40.404	333.814
Solar thermal	1	8	1	31	9.611	41.190
Biomass	30.9	50.5	37	88	49.059	127.653
Geothermal	1	3	2	26	3.458	41.496
Wave	0	5	0	15	4.125	12.375
TOTAL					**247.440**	**689.254**

Source: Calculations based on Greenpeace data and García Casals (2005) installation costs 2050 (see table 5.3.6)

Tabla 5.4.3 Size of the potential renewable energies market in Latin Aamerica

Installed capacity Latin America GW	Year				Potential Market (M€) Reference scenario	Potential Market (M€) Scenario-R
	2010	2050	2010	2050		
Technology	Reference Scenario		Scenario -R			
Hydro	157	302	159	179	261.000	36.000
Win	2	15	3	274	6.253	130.351
PV plants	0	4	1	114	3.848	108.706
Solar thermal	0	1	0	31	1.373	42.563
Biomass	4.6	11.4	11	75	17.020	160.192
Geothermal	0	3	1	16	5.187	25.935
Wave	0	0	0	7	0	5.775
TOTAL					**294.681**	**509.522**

Source: Calculations based on Greenpeace data and García Casals (2005) installation costs 2050 (see table 5.3.6)

Tabla 5.4.4 Size of the potential renewable energies market in North America

Installed capacity North America GW	Year				Potential Market (M€) Reference scenario	Potential market (M€) Scenario-R
	2010	2050	2010	2050		
Technology	Reference scenario		Scenario -R			
Hydro	189	192	192	246	5.400	97.200
Win	28	136	35	504	51.948	225.589
PV plants	2	26	2	577	23.088	553.150
Solar thermal	1	4	2	164	4.119	222.426
Biomass	20	51	25	153	77.593	320.384
Geothermal	4	11	6	118	12.103	193.648
Wave	0	3	1	51	2.475	41.250
TOTAL					**176.726**	**1.653.647**

Source: Calculations based on Greenpeace data and García Casals (2005) installation costs 2050 (see table 5.3.6)

Tabla 5.4.5 Size of the potential renewable energies market in Africa

Installed capaciaty Africa GW	Year				Potential Market (M€) Reference Scenario	Potential market (M€) Scenario-R
	2010	2050	2010	2050		
Technology	Reference scenario		Scenario -R			
Hydro	24	87	24	45	113.400	37.800
Win	1	12	1	51	5.291	24.050
PV plants	0	3	0	175	2.886	168.350
Solar thermal	1	1	1	100	0	135.927
Biomass	0.6	10.0	1	8	23.528	17.521
Geothermal	0	2	0	6	3.458	10.374
Wave	0	0	0	4	0	3.300
TOTAL					**148.563**	**397.322**

Source: Calculations based on Greenpeace data and García Casals (2005) installation costs 2050 (see table 5.3.6)

In our opinion, regulation and international agreements among the different Governments will be essential to the creation of this market.

The firm commitment from the Spanish government is a promising one and could potentially prove to be very lucrative should the renewable energies market continue to expand and should Spain keep its leadership of the early stages of development of these Technologies.

5.5. Conclusions

In this chapter we have presented some of the main consequences of a 100% renewable energy-based future for Spain's economy. Evidently these consequences are absolutely positive.

The most relevant data we have presented throughout the chapter can be sumarized in the following bullet points:

- The number of direct or indirect jobs created by a system in which 100% power generation uses renewable energy sources ranges between 282.531 and 1.188.781, depending on the electrical energy demand scenario we examine.
- The financial cost of transition to a new power generation model can be in the range of 102.401 million to 347.543 million euros. These investments are clearly smaller than if we had to meet all our energy demands with conventional or 100% nuclear power.
- Spain has access to a potential global market of between 2.06 billion and 8.09 billion euro.

Finally, we believe it essential to highlight that the scenarios herein presented could materialize if there were an appropriate regulatory framework which, through initiatives of mandate and control, amongst others, could guarantee 100% renewable energy-based power generation. Should this not be the case and such a regulatory framework were not put into place it is highly improbable that the private sector will move of its own device towards such a scenario as we have proposed.

Appendix: Costs of a 100% nuclear power generation scenario

Current debate in Spain and all over the world launched by the nuclear lobby is trying to persuade opinion that this source of energy on its own could resolve the world's future energy problems. Although at the present time technologically 100% of energy demand cannot be met using nuclear power let us try to imagine this were the case and compare this scenario with that of 100% renewable energy sources as we are proposing.

If we start with the capacity required to cover the three energy demand scenarios: high, medium and low, as proposed in this chapter, we can calculate the impact on employment and the cost of the transition to a 100% nuclear power-based generation system. In a similar way to how we calculated the transition to renewable energy, we have estimated the capacity needed to achieve this mix, and calculated the value of the investment taking into account only capital costs. The capital costs of different energy sources are compared in the table below.

Table A.1 Necessary and installed capacity for a 100% nuclear future.

Installed capacity in GW				
	Current	2050 High Demand	2050 Medium Demand	2050 Low Demand
Nuclear	7.4	147.3	103.6	67.6
Investments		139.9	96.2	60.2

Sources: Estimations based on the installed capacity proposed in chapter 3.

Table A. 2. Direct, indirect and total jobs in a 100% nuclear future

Employment in a 100% nuclear scenario	Installed capacity (MW)	Ratio jobs/MW		Jobs created				
		C, M, I	O, M	C, M, I	O &M	Direct jobs	Indirect joos	Total jobs
2050 High demand	139900	1.4	0.25	195,860	34,975	230,835	258,535	489,370
2050 Medium demand	96200	1.4	0.25	134,680	24,050	158,730	177,778	336,508
2050 Low demand	60200	1.4	0.25	84,280	15,050	99,330	111,250	210,580

Source: Estimates based on installed capacity proposed in chapter 3. Ratio of employment in construction, maintenance and installation (C.M.I) calculated using to data provided by EESI (2008). Ratio of employment in operation and maintenance (O,M) calculated using of data provided by the Nuclear Forum (2008) and MITYC (2007). Estimated number of jobs created by nuclear energy at a ratio of 1.12 indirect jobs created for every direct job. Please note that just as we did when calculating direct jobs created by RES, we have used the most conservative data on current employment levels where ever a range of data was available. Moreover, we work on the assumption that the current data are representative of the jobs which shall be created in the nuclear energy sector in the future.

Table A.3 Investments required for a 100% nuclear future [15]

Amount if investment in capital installation (million €)				
Source	**Capital cost of Nuclear million €/GW**	**2050 High demand**	**2050 Medium demand**	**2050 Low demand**
U. Chicago	1.250	174.875	120.250	75.250
MIT	1.471	205.735	141.471	88.529
EIA	1.532	214.273	147.342	92.203
Garcia-Casals current	1.618	226.309	155.618	97.382
Garcia-Casals future	2.353	329.176	226.353	141.647
Islas et.al	1.556	217.668	149.676	93.664
Average	1.629,78	228.006	156.785	98.113

Source: University of Chicago (2004), MIT (2003), EIA cited in the WNA report (no date), García Casals (2005) and Islas et al., (2003)

So, if the transition to 100% nuclear energy were to materialize only 210.580 to 489.370 jobs would be created which amounts to about half those predicted for renewable energy. The cost of installing the capacity required nuclear power to meet 100% of our energy demands in the future would amount to investments of between 75.250 million and 329.176 million euro, similar to the renewable scenario. The variation in figures is explained both by different demand scenarios and costs presented in table A.2.

Aside from the positive economic impact of renewable energy sources as opposed to nuclear energy there are other variables which also heavily influence decisions regarding our energy model. Among others, the greater potential for job creation which renewable energies offers (see part 5.2 and table A.2) and enormous potential renewable energy sources in international trade, as well as the high cost of waste management so often overlooked by estimates and public debate. [16]

The 6th General Plan for the Disposal of Radioactive Waste provides an estimate of the cost of waste management out to 2070 at current installed capacity levels. Were this capacity to be increased to fully cover demand with 100% nuclear energy these costs could rise to between 105.943 and 246.205 million euro a year depending on which demand scenario we look at. Considering that the cost of waste generated by renewable is close to zero, the issue of waste clinches the debate against nuclear energy.

15 Note that although according to the estimates which shall be published in brief by the MIT, the cost of nuclear energy will amount to 4.000$/KW, which means that the estimated figures in table A.3 are an underestimation of investment costs. See Coderch (2009).

16 These must be managed and therefore financed for thousands of years.

Table A. 4. Summary of costs (thousands of euro € 2006)
Source: MITYC (2006:163)

Item	Real up to 31/12/2005	Estimated 2006	Budget 2007-2008	Estimated 2011-2070	TOTAL
Management of Low and Medium activity radioactive waste	583.397	31.686	115.211	896.392	1.626.687
Management of expended fuel and High Radio Active Waste	1.399.732	59.838	520.333	4.264.797	6.244.700
Closure	295.818	21.888	2.601	2.230.152	2.614.791
Other activities	37.196	777	26.499	14.250	54.825
R&D	161.138	6.165	2.601	165.000	358.802
Structure	660.863	30.733	106.235	1.325.520	2.123.352
TOTAL	3.138.144	151.088	837.813	8.896.111	13.023.156

References

AEMA (2009), Señales de la AEMA 2009. Cuestiones medioambientales de capital importancia para Europa. Disponible on-line en: http://www.eea.europa.eu/es/publications/signals-2009

Blanco Silva, F. (2004), Aumento de la demanda de empleo en energías renovables. Revista Galega de Economía, vol. 13, núm. 1-2 (2004), pp. 1-11.

BOE, Real Decreto 40/2009 de 23 de enero. Disponible on-line en:
www.boe.es/boe/dias/2009/01/24/pdfs/BOE-A-2009-1170.pdf

Bower, J. (2003). UK off-shore wind generation capacity: A return to picking winners? Oxford Energy Comment. Oxford Institute for Energy Studies.

Calzada Álvarez, G. et al (2009), Study of the effects on employment of public aid to renewable energy sources. Universidad Rey Juan Carlos.

CC.OO (2006). Consideraciones de la confederación sindical de comisiones obreras: mesa de dialogo sobre la evolución de la energía nuclear en España. Mayo.

Coderch, M. (próxima aparición), El Interrogante Nuclear, Working Paper, Real Insituto Elcano

Daniel M. Kammen, Kamal Kapadia, and Matthias Fripp (2006) Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate? RAEL Report, University of California, Berkeley (2004) Corrected (January 2006). Disponible on-line en: http://socrates.berkeley.edu/~rael/papers.html

EESI (2008), jobs from Renewable Energy and Energy Efficiency, Environmental and Energy Study Institute. Fact Sheet. October 22.

Fankhauser, S. Sehlleier, F. and Stern, N. (2009), Climate change, innovation and jobs. Climate Policy 8: 421-429.

Foro nuclear (2008), Energía 2008. Foro de la industria nuclear española. Disponible en: www.foronuclear.org

García Casals, X. (2005), Renovables 100%. Un sistema eléctrico renovable para la España peninsular y su viabilidad económica. Greenpeace. Disponible on-line en:
http://www.greenpeace.org/espana/reports/informes-renovables-100
http://www.greenpeace.org/raw/content/espana/reports/resumen-de-costes-100-renovab.pdf

García Casals, X. (2005), Renovables 2050. Un informe sobre el potencial de las energías renovables en la España peninsular. Greenpeace. Disponible on-line: http://www.greenpeace.org/espana/reports/informes-renovables-2050

Giddens, A. (2009). The Politics of Climate Change. Polity Press. Londres.

Greenpeace (2008), Energy (r)evolution. A sustainable global energy Outlook. Disponible on-line en: http://www.greenpeace.org/raw/content/international/press/reports/energyrevolutionreport.pdf

http://www.appa.es/index.htm

http://www.energiasrenovables.ciemat.es/especiales/energia/espana.htm#1

http://ec.europa.eu/energy/publications/doc/statistics/part_2_energy_pocket_book_2009.pdf

http://www.eea.europa.eu/publications/state_of_environment_report_2005_1/SOER2005_Part_C.pdf

http://www.energiasrenovables.ciemat.es/especiales/energia/espana.htm http://www.greenpeace.org/raw/content/international/press/reports/energy-revolution-a-sustainab.pdf

http://www.idae.es/index.php/mod.noticias/mem.detalle/id.70/relcategoria.121/relmenu.75

http://www.iea.org/Textbase/stats/renewdata.asp?COUNTRY_CODE=ES

http://www.ree.es/sistema_electrico/pdf/infosis/Inf_Sis_Elec_REE_2007_v3.pdf

http://www.ree.es/sistema_electrico/pdf/infosis/Avance_REE_2008_v3.pdf

Houser, T. et al., (2009), A Green Global Recovery? Assessing US Economic Stimulus and the Prospects for International Coordination. WRI. February.

Islas, J, Manzini, F y M. Martínez. (2003). Cost-benefit analysis of energy scenarios for the Mexican power sector Energy. Vol 28. Num 10. pp 979-992

Istas (2008), estudio Energías Renovables y generación de empleo en España, presente y futuro. Resumen ejecutivo para CENIFER

MIT (2003). The future of Nuclear Power.

MITYC (2006), 6º Plan General de Residuos Radiactivos

MITYC (2007), La energía en España 2007. Secretaria General de Energía. Disponible on-line en: http://www.mityc.es/energia/balances/Balances/LibrosEnergia/Energia1_2007.pdf

Nieto Sainz, J. (2008), Estimación del empleo en energías renovables. CCOO

NEI (2009), Nuclear Power Plants Contribute Significantly to State and Local Economies. Nuclear Energy Institute, January.

Ruesga, S. M. (2008), Análisis económico de un proyecto de ampliación de la producción eléctrica nuclear en España. Foro Nuclear. Disponible en:
http://www.foronuclear.org/pdf/Analisis_economico_proyecto_construccion_nuevas_centrales_nucleares.pdf

Sánchez López, A. B. (2006), Empleo en PyME del sector de las energías renovables e industrias auxiliares en España. Instituto Sindical de Trabajo, Ambiente y Salud (ISTAS)

University of Chicago (2004). The Economic Future of Nuclear Power: a study conducted at the University of Chicago.

WNA (sin fecha). The New Economics of Nuclear Power. World Nuclear Association

6 Recommendations to public authorities and citizens

6.1 Political Recommendations

A) In order to achieve a fully sustainable energy model in 2050, the Government should:

1) Reaffirm its commitments with the objectives of the EU energy policy as regards climate change for 2020: 20% reduction in emissions, 20% reduction in primary energy consumption, and 20% renewable energy mix.

2) Pass a new Law on Sustainable Economy that includes as its objective the achievement of an electrical system free of emissions and nuclear energy by 2050, 100% based on renewable energies and an intelligent generation and distribution network with sufficient capabilities to store and manage energy demand. The new Law should include quantitative objectives and a precise timetable to achieve the complete modification of the energy mix in Spain, moving towards a more productive economic model.

3) Include in the new Law on Sustainable Economy the 5 explicit conditions that are detailed below, which will allow the progressive substitution of nuclear energy by renewable energies in Spain.

4) Acknowledge a new right of citizens to generate and distribute their own electricity, individually or in cooperation with current generation and distribution companies, within a new business model.

B) In order to promote renewable energies in our country, the government should introduce novel measures, such as to:

1) Reinforce tax incentives and existing bonuses for companies and citizens to lead the transition towards this new energy model. Specifically, savings should take precedence over consumption.

2) Reorganize the current system to allow further entry of renewable energies in the energy mix, without establishing limits to the development thereof.

3) Include the renewable energy sector as a priority in its economic reactivation plans and, also, include in these plans initiatives to improve the energy efficiency of our economy and energy savings in our homes in order to arise from the current crisis in a better condition.

4) Encourage that Red Eléctrica Española [the Spanish Electric Network] and companies supplying electricity modernize their transport and distribution network in order to make distributed generation possible, together with the implementation of demand management policies that encourage a more rational consumption of energy, further adapted to the generation capabilities of the new energy model.

5) Promote and facilitate solar panel installation through a program similar to the 100.000 roofs program in Germany.

6) Establish compulsory drafting of Energy Savings Plans in companies, public administrations and communities of residents.

7) Incorporate awareness measures for citizens with regard to energy savings into Education Plans.

C) In order to progressively abandon nuclear energy in Spain, the government should take into account the conclusions of this report, according to which:

1) The existing nuclear plants in Spain should start closing by the time the existing licence expires, after 40 years of service life, taking into account the following 5 conditions:

- Safety: should any of them present some safety problem, it should be closed before the expiry date.
- Substitutability: they shall be closed once there are alternative renewable energies that do not produce emissions
- Supply: they shall be closed when their substitution does not cause any problems in energetic shortage. In this sense, it is important to apply the recent agreements between Spain and France in order to facilitate the connection with Europe.
- Manageability: they shall be closed to be substituted by alternative sources of energy to allow a more adequate management of the energetic demand.
- Competitiveness: they shall be closed to be substituted by equally competitive alternative sources of energy.

2) Whilst the progressive closing down of power plants takes place pursuant to these conditions, the companies owning the plants should subscribe insurance contracts with regard to accidents, or immobilize their own funds for a value that is equal or higher than the responsibility attributed in the case of accident, like other countries, such as Germany, have done.

3) In the case of the nuclear power plant at Garoña, open since 1970, the Government may proceed by not renewing its license, designing at the same time an Economic and Employment Reactivation Plan to maintain the current level of employment in the region. The reasons for this recommendation are:

- The case of Garoña meets the five abovementioned conditions.
- Given its age and the recent safety problem[1] we consider it would be prudent to close it down.
- Given its small size it is perfectly substitutable. Last year, Spain exported the equivalent of 3 Garoña power plants in renewable energies.
- Moreover, its contribution to the energy mix has been widely compensated with the recent deployment of wind and solar energy, and closing it down would not have an impact on meeting demand and a very limited impact on wholesaling costs and on generating emissions, which in any case would be compensated with the deployment of renewable energies expected in coming years.

4) The remaining power plants should be closed at the end of their useful life, 40 years, as long as the 5 conditions mentioned above concur at the time and are accompanied by similar Reactivation and Employment Plans

5) If the license for any of the power plants should necessarily be extended for an additional period, any subsidies received from Competence Transition Costs and the level of recovery thereof should be taken into account, establishing a new reward mechanism for nuclear energy (in line with the proposals of the

1 Garoña Power Plant has been at the center of one third of the 17 incidents notified in Spain in the first quarter of 2009. Moreover, the Power Plant has requested the Nuclear Safety Committee to delay two of the 10 requirements that were imposed upon it to extend its current licence. Finally, the reports from both the Committee and ecological groups point out the existence of cracks in the Plant's vessel.

White Paper on Electricity). The new reward mechanism should save costs to the State and free up economic resources to promote investment from nuclear companies in the renewable energy sources that will have to substitute nuclear energy.

6) With all of these measures, Spain would be placed at the forefront of the worldwide energy debate.

6.2 Citizens' responsibility with regard to energy savings

The climate change challenge affects us all. For this reason, Ideas Foundaton wishes to make a few recommendations so that we can all make a more efficient use of energy in Spain:

- When we choose household appliances, it is essential to check the energy saving labels and choose Class A appliances which are the most efficient. We will save money and help the environment.
- Appliances running on batteries consume more energy than those connected to the electricity network. It is best to unplug them as soon as the battery is charged, use them until the battery runs down, and dispose of them suitably when they no longer work.
- Efficient light bulbs save up to 80% energy consumption. Although they seem more expensive to purchase, their lower consumption entails net savings for families. This type of light bulb contains mercury and must be disposed of at Recycling Centers. Furthermore, we must not forget to switch off the lights in those rooms we are not using.
- Practically all computers may be used in the operative system's energy saving mode. Switching them off after work and unplugging them also increases savings. We must modernize our computing equipment regularly since the latest technologies with regard to both screens and PCs considerably reduce energy consumption.
- Televisions, video players, PCs and all accessories are continuously consuming a considerable amount of electricity when they are in stand by mode, together with plugged battery chargers and transformers. For this reason, it is necessary to disconnect plugs or use adaptor plugs with their own switch.
- In the kitchen, we will increase energy efficiency by putting the lid on our pans and using only the water necessary to cook our food. The use of pressure cookers is recommended as it is the most efficient way to cook. We must avoid preheating the oven as doing so requires lots of energy.
- The fridge must never be close to heat sources such as the oven or the kitchen. Fridge doors must be opened the shortest time possible, verifying that they close properly. The grille on the back must never be blocked or covered in dust so that ventilation works well. The fridge must be defrosted regularly since it consumes more energy when ice builds up. It is important never to place warm food in the fridge and to defrost food by moving it from the freezer to the fridge a few hours earlier.
- When we wash our clothes, it is advisable to wash at cold temperature and without pre-wash. This will reduce energy consumption by up to 80%. It is also advisable to fill up the washing machine before washing.
- We are all aware that water in our country is scarce. In order to avoid waste, it is advisable to take a shower instead of a bath. There are water economisers for showers that save up to half the consumption of water and energy.
- Our country enjoys significant solar radiation; installing solar collectors can provide up to 70% of the hot water necessary at home, and this amount may increase to up to 100% in very sunny regions. It is already

compulsory for all new housing. Owners of old housing may also benefit easily from the advantages of installing panels on their rooftops.

- With regard to the temperature in our houses, we should respect certain logical measures in consumption. For instance, not airing the house if the heating and air conditioning are on, or avoiding the creation of unsuitable climates with excessive cold or heat that are unrelated to the time of year we live in. It is essential to improve the insulation in windows, roofs, walls and floors. These measures may reduce heating and electricity bills by more than half. Installing programmable thermostats to regulate room temperature automatically may also be very useful: for instance, higher during the day, lower during the night. We must review our air conditioning equipment periodically in order to avoid breakdowns that increase consumption artificially.

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