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Model for Evaluation of Nuclear Energy Costs in Portugal

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A mia Mamma, che da quaggiù mi ha aiutato.

A mio Babbo, che da lassù mi ha protetto.

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Abstract

One of the most important issues of the XXI century is the generation and supply of energy, in particular electricity, due to its widespread use in everyday life. In the current scenario, governments and companies face critical matters such as dependency from fossil fuels producers, possible depletion of the current reserves, and increasing in greenhouse gases. In order to prevent these phenomena, carbon free sources of energy have to be developed and integrated into the current production mix. Nuclear energy generation looks like an appealing option. In order to evaluate the competitiveness of this kind of investment, an MIT interdisciplinary research team has developed a costing model, that compares the levelised cost of alternative electricity generation technologies. In this model, nuclear energy generation is analysed together with coal and natural gas. The goal of this work is to adapt this model to the deployment of a reactor in Portugal, in order to evaluate the final cost of electricity and compare it with the actual mix of production.

Abstract

Uno dei più importanti problemi del ventunesimo secolo è quello della produzione di energia, in particolare l'elettricità, dovuto all'uso sempre maggiore che ne viene fatto nella vita di tutti i giorni. A causa di questo fenomeno, i governi si trovano ad affrontare problemi critici, quali la dipendenza dai paesi produttori di petrolio, il possibile esaurimento delle sue riserve, e l'aumento dei gas serra. Per prevenire tutto ciò, bisogna sviluppare e integrare nel mix di produzione di energia delle fonti a emissioni zero. Il nucleare è una di queste opzioni. Per valutare la competitività di questo tipo di investimento, un team di ricerca interdisciplinare del Massachusetts Institute of Technology ha sviluppato un modello di costo, che confronta diverse tecnologie di produzione di elettricità a seconda del loro costo unitario di produzione. Nel modello, il nucleare è analizzato assieme alle centrali a carbone e a gas naturale. L'obiettivo di questo lavoro è di adattare il modello per simulare un investimento in una centrale nucleare in Portogallo, al fine di valutare il costo finale di produzione dell'elettricità e compararlo con il mix attuale di produzione del paese.

Sommario

L'obiettivo di questo lavoro è l'analisi della competitività dell'elettricità prodotta tramite energia nucleare in Portogallo; i risultati verranno poi confrontati con le fonti tradizionali di energia, che già sono presenti nel Paese. Il Portogallo storicamente non ha mai effettuato investimenti in centrali nucleari, seppur abbia sviluppato nel corso degli anni sia tecnologie che veri e propri progetti di impianti: l'ultimo è stato presentato nel 2005 dall'imprenditore Monteiro de Barros, e prevedeva la costruzione di un reattore EPR da 1600 Mwe. Il progetto però ha incontrato forte opposizione da parte dei gruppi ambientalisti e delle aziende coinvolte nel business delle energie rinnovabili, e non è stato quindi portato avanti. Al giorno d'oggi, il governo portoghese non ha ancora preso una decisione finale riguardo al futuro dell'energia nucleare, in quanto il focus in questo settore è stato diretto tutto verso le energie rinnovabili. La normativa portoghese, infatti, prevede che tutta l'energia prodotta "in regime speciale" (cioè da fonti rinnovabili, di cogenerazione e da biomassa) venga acquistata da un fornitore unico, ad un prezzo stabilito di anno in anno dal governo. Dato che questo prezzo è in media più basso del costo totale di produzione, la differenza viene integrata dallo stato sotto forma di incentivi. Questo permette quindi ai produttori di energie rinnovabili di essere competitivi sul mercato iberico, che è completamente liberalizzato e aperto alla competizione. Il framework normativo è quindi un punto molto importante nella valutazione del nucleare, perchè, come sarà spiegato meglio in seguito, l'appartenenza al segmento di produzione in regime speciale garantisce di avere forti incentivi da parte del governo. Il modello utilizzato per l'analisi è stato preso da un lavoro interdisciplinare, sviluppato da un team di accademici del Massachusetts Institute of Technology, intitolato "The Future of Nuclear" power. Questo lavoro discute dei possibili scenari di evoluzione della produzione di elettricità, e mette a confronto il costo di produzione unitario di centrali nucleari, centrali a ciclo combinato e centrali a carbone. L'obiettivo finale del modello è il calcolo del Levelised Cost of Electricity (LCOE), cioè il prezzo (a livelli costanti) dell'elettricità che sarebbe necessario a coprire tutti i costi operativi, gli interessi sul debito, e che garantirebbe una remunerazione adeguata per gli investitori. Questo valore viene ricavato tramite una analisi dei net cash flow, utilizzando come tasso di attualizzazione dell'investimento il costo medio ponderato del capitale.

Per redigere il lavoro è stata utilizzata la seguente metodologia: inizialmente, è stato replicato il modello di calcolo utilizzato dal MIT per calcolare i propri costi; il capitolo 2 descrive in dettaglio la struttura del modello e le ipotesi che stanno alla base di esso. Successivamente, ai parametri originali sono stati sostituiti delle stime ragionevoli al fine di replicare un ipotetico scenario di investimento in Portogallo. Il capitolo 3 descrive queste stime nel dettaglio. Il costo così ottenuto poi, è stato confrontato con i valori medi del mercato iberico dell'elettricità e dell'energia prodotta a regime speciale. Infine sono state effettuate delle analisi di sensibilità sul prezzo finale dell'elettricità, al fine di valutare l'impatto dell'incertezza delle stime sul valore finale ottenuto. Sono stati usati, in particolare, strumenti per analizzare la variazione del prezzo a fronte di una variazione assoluta (tornado diagram) o relativa (spider graph) dei dati in input; inoltre, è stata fatta una analisi di scenario per valutare

l'impatto simultaneo della variazione di più parametri.

Le analisi hanno mostrato che il parametro la cui incertezza incide di più sull'output finale è il costo medio del capitale. Questo risultato è coerente con la tipologia di investimento che si sta considerando, in quanto le centrali nucleari sono un molto capital intensive; di conseguenza, il costo di accesso al capitale è un fattore critico per la redditività finale dell'investimento stesso.

Il prezzo dell'elettricità, ottenuto dalle analisi (5.75 cent/kWh), è superiore sia rispetto alla media del mercato iberico dell'elettricità (4.09 cent/kWh) che al costo medio di acquisizione dell'elettricità prodotta in regime speciale (5.00 cent/kWh). Tuttavia, se si considera il costo medio di produzione dell'energia in regime speciale (9.23 cent/kWh), si nota subito quanto la regolamentazione del governo influisca sulla competitività delle varie forme di energia. In conclusione, il modello mostra che il nucleare non è ancora un'opzione conveniente per il portogallo. I prezzi delle alternative correnti sono più competitivi. Questo modello però non può essere utilizzato da solo come strumento di decisione: infatti, analizza solamente il progetto solo dal punto di vista finanziario. Ciononostante, si è rilevato un utile strumento di supporto decisionale, in quanto fornisce una stima del costo finale di produzione dell'elettricità in un ipotetico scenario di costruzione di una centrale nucleare. Inoltre, permette di testare la robustezza di questi risultati a fronte di incertezza nella stima dei parametri in ingresso. Al fine di poter effettuare una decisione di investimento nel nucleare, il governo e gli investitori dovrebbero valutare anche i costi non economici che un progetto di questo tipo comporta, come costi ambientali e sociali. Possibili problematiche che possono insorgere sono: la capacità della griglia esistente di assorbire il carico di una centrale nucleare; la normativa riguardante la produzione di energia nucleare (i nuovi impianti saranno regolamentati come produzione in "regime speciale"?); l'evoluzione delle rinnovabili, in particolare per quanto riguarda i costi di produzione; la durata delle riserve di combustibili fossili e delle relative centrali di produzione. Quest'ultimo punto merita particolare attenzione, in quanto, nei prossimi 5-10 anni, alcune delle maggiori centrali termoelettriche del pese esauriranno il loro ciclo di vita. Data l'importanza di sostituire queste fonti di energia con altre a basse emissioni di anidride carbonica, il nucleare potrebbe di nuovo essere preso in considerazione.

Il modello qui studiato non intende rispondere a tutte queste domande, ma si pone solamente come strumento di supporto al fine di poter effettuare una decisione più consapevole.

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Abbreviations

BTU	British Thermal Unit
CO_2	Carbon Dioxide
CCGT	Combined Cycle Gas Turbine
CPE	*Companhia Portuguesa de Electricidade*
CPIN	*Companhia Portuguesa de Indústrias Nucleares*
EDP	*Electricidade de Portugal*
EDPR	*EDP Renováveis*
EPR	European Pressurized Reactor
ERSE	*Entidade Reguladora dos Serviços Energéticos*
ETP	*Empresa Termoelétrica Portuguesa*
FOAK	First-of-a-Kind
GHG	Greenhouse Gases
GW	Gigawatt
IEA	International Energy Agency
JEN	*Junta de Energia Nuclear*
LCOE	Levelised Cost of Electricity
LFEN	*Laboratório de Físicia e Engenharia Nucleares*
MACRS	Modified Accelerated Cost Recovery System
MIBEL	*Mercato Iberico de Electricidade*
MIT	Massachusetts Institute of Technology
Mtoe	Millions Tonne of Oil Equivalent
MWe	Megawatt Electrical
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
O&M	Operations and Maintenance
REN	*Rede Eléctrica Nacional*
SEN	*Sistema Eléctrico Nacional*
tU	Tonnes of Uranium
TWh	TeraWatthour
WEC	World Energy Council
WNA	World Nuclear Association

1 Introduction

The objective of this work is to analyse the competitiveness of the possible generation of nuclear energy in Portugal, when compared to other traditional sources of energy generation, which already exist in the country. The model used in this context reflects an interdisciplinary study done by a team of scholars in the Massachusetts Institute of Technology, called “The Future of Nuclear Power” (MIT, 2003). This work describes in depth possible scenarios of evolution of the world energy power generation system, and the role that nuclear energy will play in this scenario. The section of the MIT study on which this work is focused refers to the economic analysis of the investment project, in particular the evaluation of cash flows generated by the investment in one or more nuclear power plants, and how they affect the final cost per kilowatthour of electricity, which will be the final parameter of evaluation.

The analysis will replicate the model used by the MIT team, with the necessary adaptations related to the costs found in Portugal; several scenarios then will be evaluated.

The rest of the work is as follows: chapter one will provide a brief outline of the nuclear energy scenario, starting from a global perspective, and focusing later on the Portuguese situation; chapter 2 describes the methodological assumptions used in the analysis; the third chapter will evaluate the data obtained from the analysis, and the fourth and last chapter will conclude and summarise the work.

2 Nuclear Energy Scenario

This chapter will highlight the current situation of the global energy scenario, and it will describe more in detail the current status of nuclear energy, with its pros and cons. Afterward it is presented an analysis of nuclear energy in Europe, which describe the different policies used by each state of both the European union (EU-27) and European continent (EU-35); together with the policies, a brief survey sponsored by the Eurobarometer shows the opinion of the Europeans regarding nuclear energy and radioactive wastes. The last part of the chapter will then focus on nuclear energy and Portugal: in the beginning, the Portuguese electrical system and the demand and supply conditions are outlined; then, a brief history of the involvement of the country in nuclear matters is presented. At last, the implementation of a potential nuclear reactor in Portugal is analysed in terms of pros, cons and risks.

2.1 Global Energy overview

Electricity is believed to be, by many people, one of the greatest invention of the twentieth century. It is used nowadays for every kind sector, from residential (heating, lightening, home appliances) to heavy industry and transportation. Its consumption (and the one of primary energy, in general) has been growing steadily, making supply and production of energy one of the most important concerns of the twentieth century.

In the last half of the twentieth century, oil affirmed itself as the main source for energy generation, making al the regulatory mechanisms of society depending on crude price. Right now in Western Europe 65% of the energy demand is satisfied by oil, outdistancing natural gas, nuclear, renewable energies and coal (Correia et al., 2009).

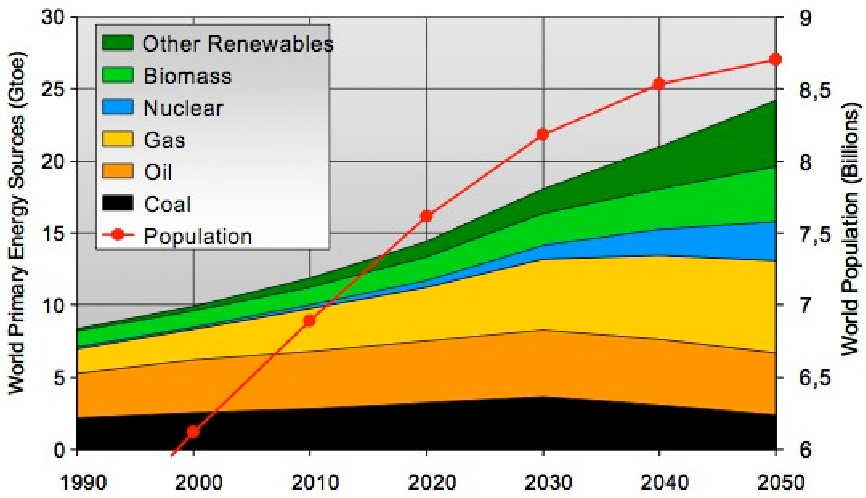


Fig. 1: IEA scenario of energy growth for a sustainable future

(Source IEA Report: "Energy to 2050 – Report for a sustainable future")

In the future, a significant increase in energy consumption is expected: a recent study done by the International Energy Agency (IEA), as illustrated in figure 1, which has been synthesised by the World Energy Council (WEC) has forecasted a growth between 2007 and 2030 of about 40% of the world primary energy demand, from 12000 to 17000 Mtoe (Million tonnes of oil equivalent). This growth is mainly lead by the demand of the new emerging superpowers, such as China and India. In order to face such strong demand, countries are forced to seek for new technologies for energy production, which are efficient and environmental friendly. This last matter is especially important since the generation of electricity from fossil fuels, is a major contributor to the emissions of carbon dioxide and greenhouse gas which is responsible for global warmth.

The awareness that emission of greenhouse gases have to be reduced is becoming each year more diffused. The Kyoto Protocol is the living evidence of this awareness; in fact, at 3rd December, 2007, 175 countries have signed the treaty. In order to reduce these emissions, the realistic options available are not many:

- increase efficiency of current energy production
- expand use of renewable energy sources (solar, wind, biomass, geothermal)
- capture carbon dioxide emission of fossil fuel-generated plants, in order to permanently sequester the carbon
- increase the use of nuclear power

2.2 Why nuclear

In 2006, the amount electricity generated from the 439 nuclear power reactors operating worldwide was 2608 TWh, 16% of the total energy produced (Correia et al., 2009). Since the beginning of the XXI century though, only 5 new nuclear reactors were authorised worldwide, of which only one is in Europe (reactor Olkiluoto III in Finland). In order to understand the reasons behind this trend, this chapter will present a brief description of pros and cons of nuclear energy production:

- As stated before, more than 65% of the total electricity produced, comes from fossil fuels, and in particular coal and natural gas. This heavy dependency may create then instability: the majority of the fossil fuels in fact, is produced in countries which are known to have a very unstable political situation, which is therefore reflected on the oil prices; and being the raw material a major component of the total production cost (46% for coal, 79% for gas fired plants), it greatly affect the final price per kilowatthour of electricity.

  Nuclear fuel (in particular Uranium) on the other hand, accounts only for 17% of the total production cost, and is produced far more stable countries than the oil ones: according to 2007 data, Canada, Kazakhstan and Russia own the highest amounts of uranium resources, with shares of 23%, 15% and 10%, respectively (WNA, 2010).
- Fossil fuel generated energy also releases into the atmosphere enormous quantities of greenhouse gases, which, as mentioned before, are responsible for global warming. Nuclear energy generation, on the other hand, has zero-level emissions of CO_2. This could turn out to

be one of the most competitive advantage of nuclear energy, in case that a carbon emission tax will be applied (as suggested in order to fulfil Kyoto Protocol standards of CO_2 emissions).

Although being a form of energy which is cheap to produce and that does not release CO_2 in the atmosphere, nuclear energy is still a controversial topic because of four still unresolved issues:

- Cost: the construction of a nuclear power plant is very capital intensive (the cost of invested capital can account from 45% to 70% of the total cost). At least in the in absence of a carbon tax, or an equivalent “cap and trade” mechanisms for reducing carbon emission, nuclear power has higher overall life costs, if compared with nuclear gas and coal.
- Safety: there is still general concern towards nuclear power, especially about environmental and health effects. These concerns rose and grew stronger after the accidents in Three Mile Islands, United States in 1979 and in Chernobyl, Ukraine in 1986, plus some other minor ones in Russia, United States and Japan. Other issues that has been growing in importance during the last years is the safe and secure transportation of nuclear materials and the protection of nuclear facilities from terrorist attacks.
- Proliferation: nuclear power entails potential security risks, notably the possible misuse of commercial or associated nuclear facilities and operations to acquire technologies and materials, in order to be able to acquire nuclear weapons production capabilities. Closed fuel cycles, in which spent fuel is reprocessed and enriched, are of particular concern, since it is possible to separate weapons-usable uranium and plutonium.
- Waste Management: the long-term management of nuclear radioactive wastes is still an open and unresolved concern. There is still no final disposition implemented on how to deal with high level radioactive wastes created at various stages of the fuel cycle. Burying the wastes (as in Yucca Mountain repository facility in the United States) is still the only option available, but it can only ease the problem, not solve it.

2.3 Economical analysis of nuclear energy

Nuclear energy is a solid candidate for an alternative to fossil-fuel generation, in terms of environmental concern, but in order to be feasible, it needs to be also competitive for the investors in terms of risks and returns. The financing for the construction of a nuclear power plant is a critical aspect in the economical portrait of this industry, since a 2005 OECD/NEA study revealed that investment costs can add up to 70% of the final cost of electricity (Grimston, 2005). Nuclear energy although, in the same conditions as other form of energy generation, is still perceived to be a more risky investment.

Some competitiveness analysis have been run by MIT and the World Nuclear Association (WNA) in order to evaluate the current potential for investing in this form of electricity generation. The analysis is based on four main parameters:

- **Investment Costs:** the capital that has to be invested in the construction of a nuclear reactor can account from 45% to 70% of the total cost (WEC, 2007). This value depends from safety issues, plant power and type, localisation, and standardisation of the plants in a country (in the case of more than one nuclear plant installed). These costs are accounted through depreciations; this means that, in case the total lifetime of the power plant is increased, the annual impact of these costs can be lower. Construction costs also affect significantly the total investment cost. Nowadays, about 60 months are required to complete a plant. The MIT study showed that in order to become competitive with coal and gas powered plants, construction times could be reduced to 4 years or less, construction cost have (and can be) cut by 25%, and the nuclear plants should be financed under the same conditions of their competitors.

- **Operations and Maintenance (O&M) costs**: O&M and maintenance cost have been falling for the past 20 years (44% shrink in the USA in the time span between 1990 to 2003, from 2,07 US-cent to 1,28 US-cent) (WNA, 2005) due to an increase in availability factor, which allowed the fixed cost to be spread on a wider basis. It is important to notice that these increases in availability have been done at the same or greater level of security. One of the technical factor that more contributed to the increase in availability is the level of fuel burn up: a higher burn up, in fact, allows both for longer fuel load cycles (intervals between refuelling), and hence shorter planned outages, and reduced fuel cycle costs.
- **Fuel costs**: According to WEC, nuclear fuel prices are, on average, about 0,5 US-cent/kWh. As stated in a WNA report, the fuel's contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect. For instance, typically a doubling of the uranium market price would increase the fuel cost for a light water reactor by 26% and the electricity cost about 7% (whereas doubling the gas price would typically add 70% to the price of electricity from that source) (WNA, 2010).
- **Decommissioning costs**: Decommissioning costs include: dismantling the nuclear power plant, waste treatment and disposal of all types of radioactive waste, security, site cleanup and project management. Dismantling and disposal represents a major share, each accounting for approximately 30% of the total decommissioning cost. Decommissioning represents only a tiny fraction of the total costs, and is covered by a decommissioning fund which represents a percentage of the production revenues.

In conclusion: nuclear energy requires higher capital investment, but has lower fuel cost than oil and natural gas. This feature makes it less sensitive to raw material price fluctuations. Furthermore, its competitiveness is increased in the presence of a carbon emission tax, which will make fossil fuel sources less convenient for investors. Even though nuclear energy production has had a decreasing trends, it is about to enter a new renaissance since, as stated in the WNA report “The new Economics of Nuclear power”: “In most industrialised countries today, new nuclear power plants offer the most economical way to generate base-load electricity – even without consideration of the geopolitical and environmental advantages that nuclear energy confers” (WNA, 2005).

2.4 Nuclear power in Europe[1]

The future of nuclear power in Europe has been controversial for the past two decades, largely as a result of the Chernobyl accident in 1986. Following a prolonged “out in the cold” period, there is a growing for a re-assessment of the role of nuclear power in Europe’s energy mix. The fact that nuclear energy produces virtually no CO2 emissions, coupled with developments in technology and concerns over the increasing cost and uncertainty of oil and gas supplies, are gradually transforming nuclear power into an attractive prospect. A lot of studies on foresee a strong growth in energy demand in Europe, as well as the rest of the world, in the next years, and many countries are looking to nuclear power as a low-carbon source to introduce into their energy mix.

2.4.1 Current situation

As of 31 December 2004, the installed generating capacity of Europe totalled 1,045 gigawatts (GW), some 599 GW (57%) whereof was fossil fuel fired, 228 GW (22%) was hydro, and 172 GW (17%) was nuclear. The majority of fossil fuel fired generation capacity is located in Italy, Germany, Russia, Spain and UK. Historically, this kind of energy is produced in countries where there is abundance of domestic fuel production (Oil and Gas for Russia, Coal and lignite for Germany, coal, oil and gas for UK). Italy is the only exception, since it produces more than 70% of its energy through fossil fuel fired plants and without having significant fuel production.

Concerning nuclear power, as shown in table 2.1, there are a total of 195 nuclear power plant units with an installed electric net capacity of 168,484 MWe in operation in Europe and 17 units with 14,710 MWe were under construction in six countries.

1 Europe will be used in this paragraph to indicate both the European continent and the European Union (EU-27). Where possible this distinction will be made clear.

Country	in operation		under construction	
	number	net capacity MWe	number	net capacity MWe
Belgium	7	5863	-	-
Bulgaria	2	1906	2	1.91
Czech Repuplic	6	3678	-	-
Finland	4	2696	1	1600
France	59	63260	1	1600
Germany	17	20470	-	-
Hungary	4	1859	-	-
Netherlands	1	482	-	-
Romania	2	1300	-	-
Russian Federation	31	21743	9	6894
Slovakian Republic	4	1711	2	810
Slovenia	1	666	-	-
Spain	8	7450	-	-
Sweden	10	8958	-	-
Switzerland	5	3238	-	-
Ukraine	15	13107	2	1900
United Kingdom	19	10097	-	-

Table 2.1: Nuclear power plants in Europe, in operation and under construction, as of Jan 2010

(Source: European Nuclear Society, 2010)

In terms of electricity generated by nuclear energy in 2008 France holds the top position with a share of 76.2 % followed by Lithuania with 72.9 %, Slovakian Republic with 54.4 %, Belgium with 53.8 %and

Sweden with 42 %.

2.4.2 Attitude of Europeans towards Nuclear Energy

In June 2008 the European Union published a survey regarding the attitude of European citizens towards the topics of nuclear energy and radioactive wastes (TNS, 2008). It presents the following results: support for nuclear energy in Europe has significantly increased over the years. At the moment of the survey, the share of population who was in favour of nuclear energy (44%) nearly equalled the share of the opposition (45%). The study also highlighted that there is a strong correlation between the consensus for nuclear energy in a country with the presence of Nuclear Power Plants (NPP) in the country itself:

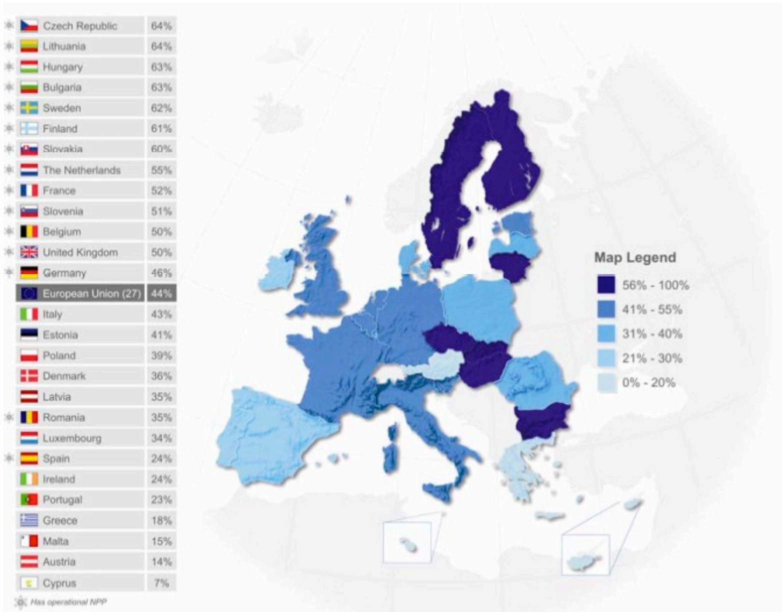


Fig. 2: Percentage of Citizens in Favour of Nuclear Energy

(Source: TNS, 2008)

With the exception of Spain and Romania, all the countries which have operational NPP have higher than average favourable opinion towards the production of nuclear energy.

The main concern for those who oppose the use of NPP is the safety aspect of managing radioactive wastes. If this aspect were to be resolved, nearly 40% of this group would be willing to change their mind on nuclear energy. Although an most of the European citizens believe that is fundamental to find a solution for managing high-level radioactive wastes, more than 70% believes that there is no safe way to deal with this problem. The presence of NPP in a country also influences this factor: citizens that live in a country with operational plants are more knowledgeable about nuclear wastes and nuclear energy in general. Knowledge level are also higher among supporter of nuclear power and of people who feel well informed about it, compared to those who are against it or feel badly informed about it.

In conclusion, there is an increasing consensus in the European union for what concerns nuclear energy, and increasing the level of information about nuclear waste management could probably help to increase this trend even further.

2.4.3 Future of nuclear energy in Europe

The nuclear sector in Europe is at a critical decision point nowadays: by 2020 more than 80% of the total installed capacity will be more than 30 years old (WEC, 2007). This means that most of the plans will retire in the next twenty years most of the plants will end their life cycle, and the decision on how to face this challenge will affect the energy scenario for many decades to come. Currently the European policy makers and the energy industry face three major challenges:

- Stabilising or reducing the amount of GHG emissions
- Ensuring security of energy supply
- Keeping prices of energy affordable and maintaining competitiveness

At the moment, there is no common policy among the various countries of the European Union, concerning nuclear energy: Belgium is the only country that has an active nuclear phase-out plan. Czech Republic, Finland, Hungary, Italy, Lithuania, Romania, Russia, Poland, Slovakia, Slovenia, Sweden and UK are currently building or considering building new power plants. Germany, Netherlands and Spain have nuclear reactors but no plans for either constructing new ones or prematurely close the existing ones. Austria, Denmark, Greece, Ireland and Norway have no nuclear plants and have regulations and laws restricting possibility to building nuclear power plants within their territory.

In conclusion, the future of nuclear power in Europe depends mainly on one issue: winning over the public opinion. Nuclear energy is still viewed as a negative, mainly due to the proliferation, cost, and waste disposal issues. In order to guarantee the development of this kind of energy production, public awareness about energy issue has to be increased by using factual information and comprehensive and efficient communication campaigns.

2.5 Portugal and Nuclear energy

2.5.1 Current situation

2.5.1.1 Electricity system in Portugal

Under the new regulatory framework, resulting from the implementation of EU directives on electricity (Directive 2003/54/CE) and gas (Directive 2003/55/CE), the Portuguese national electricity system (*Sistema Eléctrico Nacional*, or SEN), can be divided in five major functions, as shown in figure 3 below. Each of these functions must be operated by a single legal organisation, independently from the others.

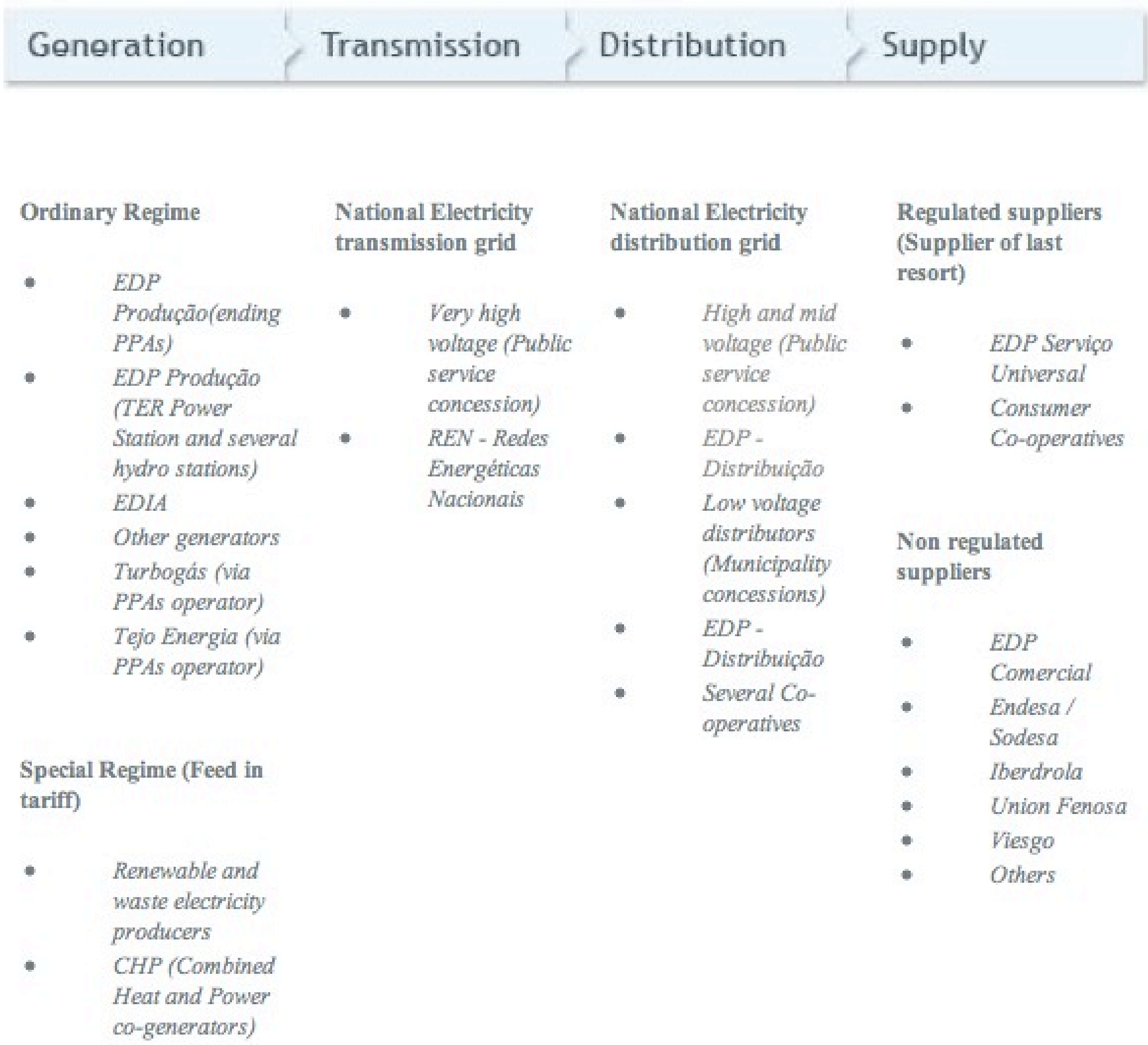


Fig. 3: National Electrical System Value Chain

(Source: REN)

- **Electricity Generation**: electricity generation can divided in two major regimes: ordinary regime generation, which refers to the production from standard fossil fuelled plants and large hydro-electric plants, and special regime generation, which refers to electricity produced from renewable and alternative indigenous sources. This sector is fully opened to competition, after obtaining licenses and approvals. Under the new framework, the last resort supplier (currently EDP Serviço Universal, S.A.) must acquire all the electricity produced through the special regime generation. The electricity produced in ordinary regime can be sold to the final consumer or to electricity suppliers, through a specialised market like the Iberian Electricity Market (*Mercado Ibérico de Electricidade,* or MIBEL). Electricity generated through an hypothetical power plant will fit into the ordinary regime generation parameters, and thus regulated accordingly.
- **Electricity Transmission**: electricity transmission in Portugal is done through the national

energy grid, which is currently managed by REN Rede Electrica Nacional through a concession of 50 years granted by the Portuguese government in 2007.

- **Electricity Distribution:** Electricity distribution is done through the national distribution grid at three levels: high, medium and low voltage. The distribution through the high and medium voltage grids has been granted to EDP Distribuição by the Portuguese government, while the low voltage distribution is awarded by local municipalities, mainly to EDP Distribuição as well.
- **Electricity Supply**: The supply of electricity is now fully open to competition, subject to obtaining the requisite licenses and approvals. Suppliers are free to buy and sell electricity and to access the distribution grids, upon payment of fees set by the Regulatory Entity for Energy Services (*Entidade Reguladora dos Serviços Energéticos*, or ERSE). Being an activity subject by competition, consumers are free to choose their suppliers and switch among them without paying additional fees. In addition, EDP - Serviço Universal, S.A. (an independent entity established for this purpose), together with few local low voltage distribution concessionaires has undertaken the new role of the last resort supplier, which is subject to regulation by ERSE. The last resort supplier is responsible for the purchase of all electricity generated by special regime generators, an obligation which until January 1, 2007 was carried out by REN Rede Eléctrica, and for the supply of electricity to customers that purchase electricity under tariffs or regulated customers and is subject to universal service obligations. This role is temporary, and will exist until the liberalised market is fully competitive and the concession contracts have expired as provided for in Directive 2003/54/CE.
- **Operation of the Electricity Markets:** these markets operate on a free market basis and are subject to authorisations jointly granted by the Minister of Finance and by the Minister responsible for the energy sector. Generators operating under the ordinary generation regime and suppliers, among others, can become market members. In the case of a Nuclear Plant entering the market, it could sell its electricity in one of these markets, such as MIBEL.

2.5.1.2 Supply and Demand Conditions

Table 2.2: Main Indicators for Portugal and European Union

(Sources: INE/IEA)

	Portugal	EU27 Average
Energy Production (Mtoe)	4.62	31.87
Net Imports (Mtoe)	21.82	36.42
Electricity Consumption (TWh)	51.56	117.34
Consumption per person (MWh/person)	4.86	6.39
CO_2 Emissions (Mt CO_2)	55.20	145.42

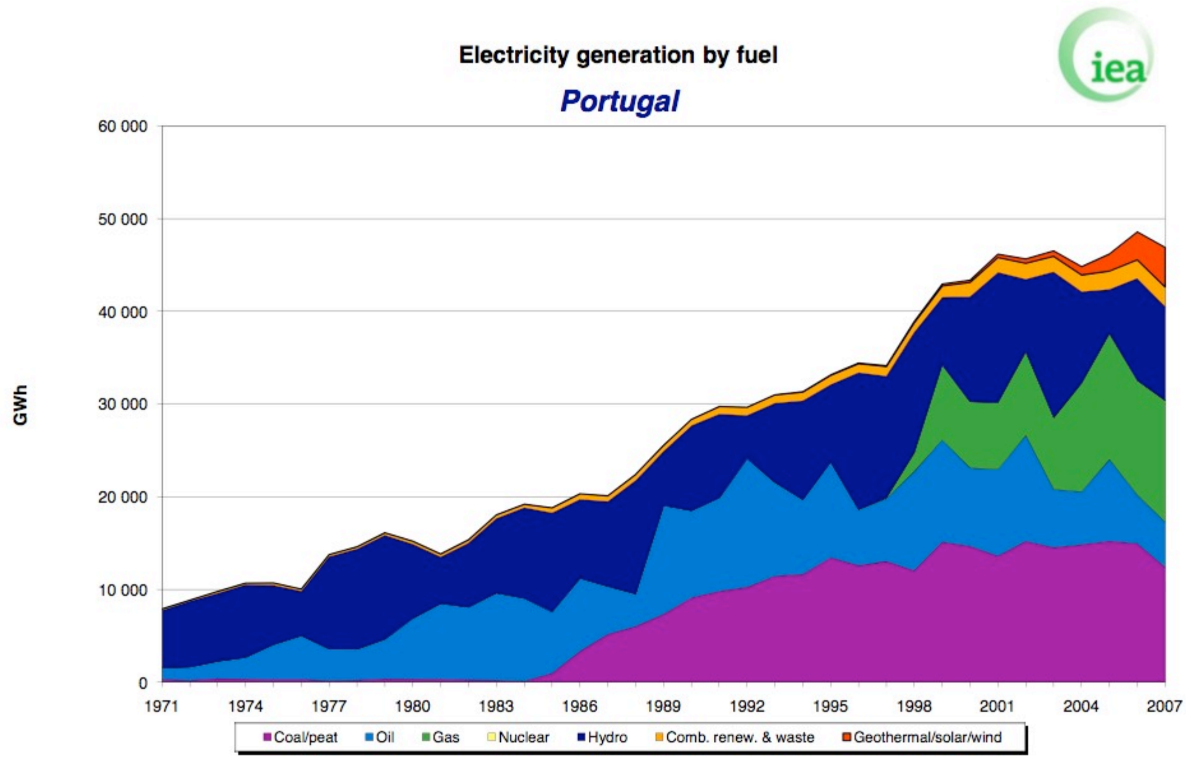


Fig. 4: Evolution of Electricity Generation in Portugal

(Source: IEA)

Portugal is a country with an elevated energy dependency, mainly due to its lack of primary energy sources (oil, coal and gas). As shown in table 2.2, In 2007 the total electricity consumed added up to 51.56 TWh. This value is more than 20% smaller than the EU-27 average, mainly due to the still ongoing development of the Portuguese economy and the reduced need for heating systems in the country.

The internal production can only satisfy a small portion of this demand: figure 4 shows the evolution of the generation mix in the country in the past years. The great majority of the production (more than 60%) comes from fossil fuel fired plants. This two factor make Portugal a highly fossil fuel-dependant country, which, as highlighted in chapter 2.2, Is geopolitically disadvantageous. Adding nuclear energy to the mix could contribute to solve the problem of dependency (more autonomous generation of electricity), differentiation (nuclear energy would increase the share of CO_2 free energy sources).

2.5.2 History of Nuclear Energy in Portugal

Portugal starts approaching the nuclear matter in 1948, when the *Instituto para a Alta Cultura* (Superior Culture Institute) proposes to the Ministry for National Education the creation of a commission of geologist and physicists to study Uranium supplies and mining technologies, which although never takes place. At the same time the 2nd National Engineering Congress suggests the Congress to propose a general plan for the utilisation of atomic energy.

The first approved proposal arrives in 1952, after an early rejection in 1950, when the National

Education Ministry presents an item for the National General Budget specifically to finance studies related to the development of nuclear energy. During October of this year, the temporary Commission for Nuclear Energy Studies is created, which will form, in partnership with the Portuguese universities, the first centres for nuclear energy researches, both pure and applied.

In march 1954 the Nuclear Energy Board (*Junta de Energia Nuclear,* or JEN) is created; its role consists initially in an inspection of the current situations of Uranium supplies both in Portugal and its colonies. Later on, the JEN will create the Laboratory for Nuclear Engineering and Physics (*Laboratório de Física e Engenharia Nucleares*, or LFEN), which will be inaugurated in 1961 as the first centre for education and research that could benefit both universities and industries.

In this period the first proposal for building a nuclear plant start to arrive: in 1955 first, professor Alberto Abecassis Manzanares, of Instituto Superior Técnico, states the importance of building an experimental low power reactor (between 5000 and 10000 kW), which will serve to gather enough experience for handling higher power reactors later; in 1957, at the 2nd Portuguese Industry Congress, Doctor Armando Gilbert presents a communication in which he underlines the importance of beginning to use nuclear energy, starting from 1965.

Later on, the first Reunion of Portuguese Technicians for Nuclear Energy, this deadline will be extended by about 10 years. The first concrete step is taken in April 1958, when the Portuguese Association of Nuclear Companies (*Companhia Portuguesa de Indústrias Nucleares*, or CPIN) is created: CPIN, in 1959, begins to intensify the studies and to form engineers for the installation of a first pilot nuclear plant, with an approximate power of 50 MWe, to be completed by 1965. Three years later it presents the preliminary studies of a 230 MWe Nuclear Plant equipped with a boiling water reactor. In 1964 CPIN sells its assets to the Portuguese thermo-electric company (*Empresa Termoelétrica Portuguesa*, or ETP), which presents on year later a joint project with Electricity Company of Sevilla for a nuclear plant close to Rio Guadiana.

In 1969 ETP presents the preliminary studies regarding the choice of a site for the first portuguese nuclear plant; from the six initial hypothesis, the choice will be done between Ferrel and Sizandro, which will be made operational by the end of the decade. Three years later, the Portuguese electrical company (*Companhia Portuguesa de Electricidade*, or CPE) foresees 1979 as the year in which the first portuguese reactor will start its activity. The plan is to build four reactors at different times (between 1981 and 1989), with an investment of about 30 million contos, in 1972 prices (about 350 million euros nowadays). In 1974 CPE contracts a consulting firm to evaluate the best site for the installation of the first Portuguese nuclear power plant. Ferrel is chosen as the best best option.

Another study is exposed in December 1977 to the secretary for energy and mines, which presents the possibility of building 4 to 7 1000 MWe nuclear reactors between 1990 and 2000. The government though decides to delay the decision.

The national energy plan in 1982 includes the opening of a first nuclear plant, of 950 MWe power, in 1995, that will start a nuclear program that will bring up to 6000 MWe of installed power by 2010. The 8th Constitutional Government does not approve this plan, but sends it to be discussed in a public debate.

The following version of the National Energy Plan, in 1984, also plans the installation of three 950 MWe reactors between 1998 and 2010, but the decision process stops at the location analysis because the International Atomic Energy Agency will not arrive to a formal position on the issue.

The official halt to a possible nuclear energy plan comes from the State Secretary of Environment of the 10th Government in 1986; although the Minister for Industry and Commerce and the State Secretary of Industry do not agree with this position, the First Minister rectifies it and it becomes and official government decision.

In the following 20 years, nuclear energy becomes a taboo for Portugal: the 13th government (1995/1999), lead by António Guterres, decides do adopt an energy policy that focuses on renewable energies. At the end of the parliamentary term, the government emits the joint order n°531/99[2], in which it formalise the position of Portugal on the nuclear energy issue at international level. The overall position is a gradual retirement from both the industry and the research and development scene.

It is only in February 2005 that nuclear is brought once again to attention: the businessman Patrick Monteiro de Barros, together with other promoters, proposes the construction of a 1600 MWe EPR reactor; the possible location for the plant is not revealed, although rumours state that Mogadouro, close to the Douro river could be the one. The project never arrives to be debated. The strong opposition from the environmentalist organisations and companies involved in the renewable energy business forbid not only the further development of Monteiros de Barros project, but of the nuclear option in any form (Correia et al., 2009).

Nowadays, the government did not taken a final decision concerning the future of nuclear energy in Portugal.

2.5.3 Cost-Benefits Analysis

2.5.3.1 Benefits

2.5.3.1.1 Environmental benefits:

Building a nuclear plant allows to reduce the emission of greenhouse gases. For example, if we consider the scenario formulated by J.H. Gittus (figure 5), in which fossil fuels are gradually replaced by nuclear and renewable energy sources, Portugal could arrive to produce around 70% of its energy from carbon free sources by 2025, achieving an absolute reduction of 20% from the current levels of emissions.

2 Despacho Conjunto n° 531/99, 17 Jun 1999. Diário da República, n°151, 2nd Series, 1 Jul 1999, p.9452.

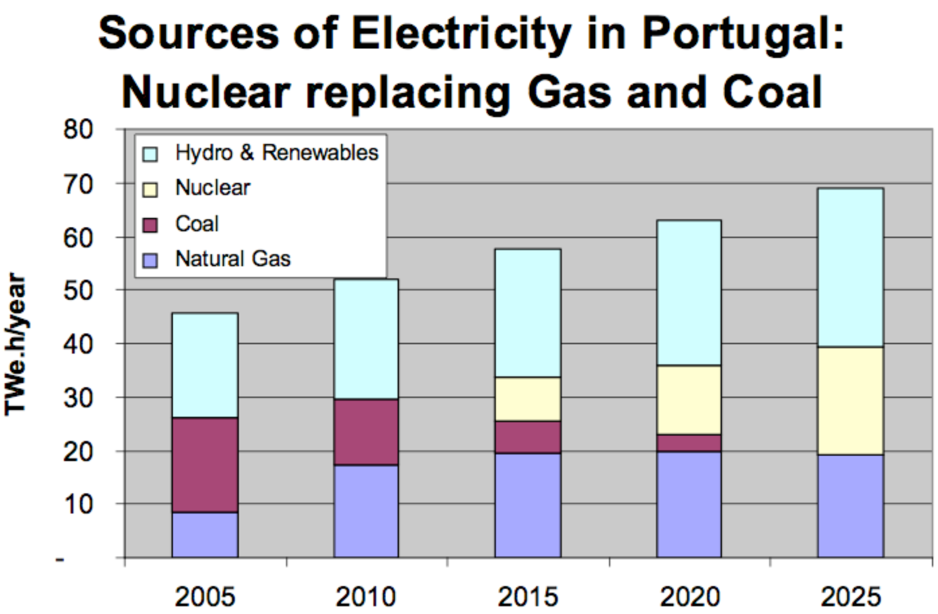


Fig. 5: Hypothetical Energy Growth Scenario, with nuclear energy replacing fossil fuels

(Source: Gittus, 2007)

2.5.3.1.2 Geopolitical benefits:

Nuclear energy allows more security in the supply of energy, since it diversifies the mix and reduces dependency from oil and coal, which in Portugal is imported almost at 100%; uranium, in fact, is present in Portugal in three main mines: Trás-os Montes, with reserves 800 tU; Beiras, with 2350 tU; Alto Alentejo, with 3650 tU (Correia et al., 2009). Furthermore, it can be easily imported from countries which have stable political situations, like Canada and Australia, for example. Investing in nuclear energy allows to stabilise price of hydrocarbons, since the demand for fossil fuels will be reduced. This will minimise the impact of energy crisis, which will increase the feeling of security for investors and consumers.

2.5.3.1.3 Socio-Economical benefits:

The construction of a nuclear plant helps developing the region in which it will be localised. In fact, it creates jobs, initially for constructing and then for maintaining the structure; this benefits all the industries related to the sector (construction, cement, electrical plants etc...). Furthermore, in the surrounding of the plant it could be convenient to develop industries which require high amount of energies, like metallurgical ones.

Finally the low costs of nuclear energy allow for a reduction of the consumers electrical bill, and the reduction of the imports of energy could allow Portugal to turn from an importing to an exporting country, thanks to the liberalisation of the energy market.

2.5.3.2 Costs

2.5.3.2.1 Environmental Costs

Radioactive wastes have a very high decay time, so their handling, treating and storing procedures have to be approached carefully and in detail. It is necessary to have a transparent in order to demonstrate that the depository of these wastes is not harmful to the people and the environment.

2.5.3.2.2 Socio-Economical Costs

The construction of a nuclear power plant is still not considered an attractive investment: the project has a high initial capital cost, it requires at least 6 years to be completed, and about 10 years to reach the break even point. As shown in the Eurobarometer survey (TNS, 2008) mentioned in Chapter 2.4.2, Portuguese citizens still show resistance against the production of energy through nuclear fission (only 23% of the people interviewed declared himself in favour), probably because the fear from the Chernobyl accident has still not passed. All of these factors increase the perceived risks and thus the cost of capital required by the investment, which then increases itself the cost of the overall project.

2.5.3.3 Risks

Risks related to a nuclear new build are intrinsically related and overlap each other, but they can be classified into four different categories (Finion and Roques, 2008):

- **Regulatory and political risks:** nuclear plants, unlike other investments in the electricity sector, have more difficulties in obtaining construction and operating license. Furthermore, the regulatory framework is likely to change over the year; this can scare investors away, given the long pay-back periods of the investment. Nuclear energy is also subject to heavy politicisation, which can undermine the stability of the regulatory framework.

- **Construction risks:** often, nuclear builds are large-scale, first-of-a-kind (FOAK) or one-of-a-kind project; in these kind of projects risk is increased because of the lack of experience and because of the new designs implemented. In order to mitigate these risks, the quality of project management is essential.
- **Operating and performance risks:** nuclear plants, like other FOAK projects, may have lower reliability over their life time. Furthermore, the advanced technologies used make it difficult for the investors to estimate this reliability; this informational asymmetry can either lead to a higher expected return on investment, or even prevent investors from entering the project.
- **Market risks:** market risks are mainly related to the sale of electricity. The attractiveness of a nuclear plant investment depends on the fluctuation of fuel prices (which affect more fossil fuel generation technologies)and on the price cap on CO_2 emission (which make nuclear energy an attractive investment, since it is a carbon-free source of electricity). The high capital intensity of a nuclear investment instead, make it riskier compared to smaller modular investments, like CCGT plants.

There are also some risks, which are specifically to the Portugues scenario:

- The Portuguese government is currently not interested in developing nuclear energy, since its focus for carbon free sources of energy is on renewable ones. Furthermore, the strong opposition of many stake-holders (environmentalist groups, investors of the renewable sector, politicians) makes nuclear technology a difficult topic to discuss and develop.
- Portugal has a lack of human resources in the nuclear sector and a lack of experience in constructing and exploring nuclear projects. This is a problem that cannot be solved immediately, but it can be mitigated by importing know-how from countries which already make intensive use of nuclear technology (like France), or by outsourcing to countries which are investing a lot in nuclear research and development (like China and India).

3 Methodology

The cost model upon which this analysis is based, performs the calculation of the real levelised cost of electricity (LCOE); this means calculating the constant (real) price of electricity that would be necessary in order to cover all the operating expenses, interests and obligations to the investors.

The economical model allows to compare technologies that have similar operating characteristics; in the case studied in this paper, this translates into comparing generation technologies with similar capacity factors. The LCOE can be calculated using discounted cash flow analysis: the method consists projecting revenues and expenses over the lifetime of the project, and discount them at a rate which is sufficient to satisfy debt obligations and cost of capital required by investors. The table below shows the parameters used throughout the model (which will be fully shown in the appendix of the dissertation):

Table 3.1: Model Input Parameters

(Source: MIT, 2003)

Variable	**Symbol**	**Value**
Inflation Rate	i	3.00%
Interest Rate	r_d	8.00%
Expected return to equity investors	r_e	15.00%
Debt to Equity ratio	D/E	1
Marginal composite corporate income tax rate	τ	38.00%
Debt term **[years]**	N_d	10
Net capacity [**MWe**]	L	1000
Capacity factor	Φ	85.00%
Plant Life **[years]**	N	40
Heat Rate **[BTU/kWh]**	HR	10400
Overnight Costs **[$/kWe]**	C_0	2000
Construction Period **[years]**	N_d	5
Depreciation Schedule **[years]**		10
Decommisiong cost **[million $]**	C_{Decom}	350
Incremental Capital cost **[$/kWe/yr]**	C_{Incr}	20
Fuel costs **[$/mmBTU]**	C_{Fuel}	0.47
Real fuel escalation	e_f	0.50%
Nuclear waste fee **[mill/kWh]**	C_{Waste}	1
Fixed O&M **[$/kWe/yr]**	C_{OMf}	63
Variable O&M **[mills/kWh]**	C_{OMv}	0.47

3.1 Calculation of the Levelised Cost of Electricity

The main objective of the model is to find the final cost per kilowatthour that is able to repay debt obligation and satisfy the return on equity required by the investors. In order to calculate this value, an iterative process using discounted cash flow analysis is used. The method uses the following formula:

$$NPV=\sum_{n=0}^{N}\frac{CF_n}{(1+r)^n} \quad \textbf{(1)}$$

Where *NPV* is the Net Present Value of the investment, CF_n is the Cash Flow for the year *n*, *N* is the lifetime of the project, and *r* is the rate at which the cash flows are discounted over the years. The cash flows required for the evaluation are calculated in an equity owner vision, which means that amortisations and depreciations are added to the gross income:

$$CF_n=EBIT+C_{amm,n}+C_{depr,n} \quad \textbf{(2)}$$

The particular rate of discount that is used is the Weighted Average Cost of Capital (WACC), which is the rate that a company is expected to pay on average to all its security holders to finance its assets.:

$$WACC=\frac{D}{D+E}r_d+\frac{E}{D+E}r_e \quad \textbf{(3)}$$

The minimum cost which allows to have a NPV equal to zero is the Levelised Cost of Electricity.

$$\sum_{n=0}^{N}\frac{CF_n(LCOE)}{(1+WACC)^n}=0 \quad \textbf{(4)}$$

3.2 Construction of the Model

The following sections illustrate how each line of the model is calculated.

3.2.1 Revenues

The sole source of revenues for the nuclear power plant is the sale of electricity. It is assumed that all the electricity is sold each year in an unregulated market. The yearly revenue R_n is calculated as the product of the quantity of electricity *Q* produced by the plant times the yearly price per kilowatthour P_n, adjusted by the inflation rate:

$$R_n=Q\cdot P_n \quad \textbf{(5)}$$

$$P_n=P_0\cdot(1+i)^n \quad \textbf{(6)}$$

$$Q=\frac{L}{10^3}\cdot\Phi\cdot 8760 \quad \textbf{(7)}$$

Where *L* is the net capacity and $\Phi$the capacity factor. In the case studied, a plant of 1000 MWe, with a 85% capacity factor, is able to produce up to 7446 GWh of electricity each year.

3.2.2 Operating Expenses

Operating expenses are all the expenses that occur while running the power plant. They include fuel expenses, waste management, operating and maintenance costs. Incremental capital expenditures are treated as well as operating expenses (this is a simplification in order to avoid another depreciation schedule. Since the expenses occur every year, the error introduced is small). Table 3.2 below Illustrates all the operating expenses together with their values and formulas.

Table 3.2: Operating Expenses

(Source: MIT, 2003)

Expense	Notation	Formula
Fuel	$C_{n,fuel}$	$C_{Fuel} \cdot HR \cdot Q \cdot (1+e_f)^n$ **(8)**
Waste Fund	$C_{n,waste}$	$\frac{C_{Waste}}{10^3} \cdot Q \cdot (1+i)^n$ **(9)**
Fixed O&M	$C_{n,omf}$	$C_{OMf} \cdot \frac{L}{10^6} \cdot (1+e_{om})^n$ **(10)**
Variable O&M	$C_{n,omv}$	$\frac{C_{OMv}}{10^6} \cdot Q \cdot (1+e_{om})^n$ **(11)**
Decommissioning	$C_{n,decom}$	$C_{Decom} \cdot (1+i)^N \cdot SFF_0$ **(12)**
Incremental Capital	$C_{n,incr}$	$C_{Incr} \cdot \frac{L}{10^3} \cdot (1+i)^n$ **(13)**

3.2.3 Asset Depreciation

Depreciation is a method of attributing historical cost of an asset across its useful life. It is important to calculate annual tax liability. In the case studied, the asset depreciates according to Modified Accelerated Cost Recovery System (MACRS) guidelines, assuming a 15 year asset life. The MACRS is the current methodology in the U.S. tax system for recovery of capitalised costs of depreciable tangible property other than natural resources. The depreciable asset base is based on nominal expenditures. Table 3.3 below shows the applicable percentage for a 15 year property class:

Table 3.3: MACRS applicable percentage for property class

(Source: IRS, 2010)

Recovery year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Applicable Percentage	5.00%	9.50%	8.55%	7.70%	6.93%	6.23%	5.90%	5.90%	5.91%	5.90%	5.91%	5.90%	5.91%	5.90%	5.91%

3.2.4 Capital Investment

The overnight costs C_0 are allocated at the year production begins, over the construction period T_C^*. The cost profile that is used to allocate the expenses over the construction period is one that peaks at

* It is important to notice that all the capital expenditures are counted at the beginning of the year in which they occur, and all the revenues and operating expenses are assumed to occur at the end of the year.

mid-construction, and which is characterised by a sinusoidal function (MIT, 2003):

$$F_n = \int_{\bar{n}}^{\bar{n}+1} \frac{\sin\theta}{2} \cdot d\theta \quad \textbf{(14)}$$

$$\text{where} \quad \bar{n} = \frac{n \cdot \pi}{T_C}$$

Table 3.4 below illustrates the representative construction outlays:

Table 3.4: Representative Construction Outlays

(Source: MIT, 2003)

Year	**-5**	**-4**	**-3**	**-2**	**-1**	**Total Cost**
Expenditure Fraction	9.55%	25.00%	30.90%	25.00%	9.55%	100%
Construction Outlay (nominal $/kWe)	165	444	566	471	185	**1831**
Actualized Cost (real $/kWe)	191	500	618	500	191	**2000**

Note that the cost are specified in constant dollars of the year production begins, so each year the capital expenditure is deflated to current year dollars. The actualised cost is given by the following formula:

$$X_n = F_n \cdot C_0 \cdot (1+i)^n \quad \textbf{(15)}$$

Where X_n is the outlay in year n, F_n is the fraction of the overnight cost allocated to year n, and i is the rate of inflation.

3.2.5 Debt repayment schedule

The debt is repaid through constant fees. The total amount is given by the calculating the fraction of the initial capital investment that is repaid by debt, and actualising it at the debt interest rate:

$$D_{tot} = \sum_{n<0} X_n \cdot \frac{D}{D+E} \cdot (1+r_d)^{-n} \quad \textbf{(16)}$$

where X_n is the construction outlay for year n. In the case studied, the total debt amounts to 1154 million $. The annual fee R is calculated using the perpetuity formula:

$$R = D_{tot} \cdot \frac{r_d (1+r_d)^{nd}}{(1+r_d)^{nd} - 1} \quad \textbf{(17)}$$

With a 8% interest rate, and a 10 years time span, the yearly fee is about 172 million $. Table below shows the total debt repayment schedule:

Table 3.5: Debt Repayment Schedule

Year	1	2	3	4	5	6	7	8	9	10
Residual Capital	1154	1074	988	895	795	687	570	444	307	159
Interest Due	92	86	79	72	64	55	46	35	25	13
Fee	172	172	172	172	172	172	172	172	172	172
Capital Payment	80	86	93	100	108	117	126	137	148	159

The interest payment is a tax-deductible expense, so it is also used to calculate the total taxable income.

3.2.6 Tax Liability

The tax liability, T_n, is simply the product of taxable income and the composite marginal corporate income tax rate, assumed to be 38% in the base case in the United States:

$$T_n = \tau \cdot [R_n - C_{n,Op} - C_{n,incr} - D_n - I_n] \quad \textbf{(18)}$$

4 Portuguese Case Study

In the following chapters we will outline the methodology used to apply the MIT model to evaluate a possible implementation of a NPP in Portugal. The first chapter (4.1) outlines the main differences between the Portuguese and American scenario. Afterward, in chapter 4.2, for each section of the model (e.g. operational costs, costs of capital) we will outline the sources used for collecting the data, the methodology used to process this data and perform the estimation, and the risks implied in each estimation. The model considers an hypothetical power plant that will start operating in 2010, thus it assumes that all the overnight operations are already taken care of; the exploration period is 40 years long. The final chapter (4.3) will summarise and present the results.

4.1 Main Features of the Portuguese Scenario

The original cost model by MIT was developed for the US energy market, which is completely unregulated and has already many operating nuclear power plants. In order to apply this model to the Portuguese market, we need to take some factor into consideration:

First of all, the energy market in Portugal is regulated; a last-resort-supplier has to purchase all the energy produced in special regime (for more information, see chapter 2.5.1.1). In order to evaluate a NPP project, it is important to understand whether the electricity produced in this way will be regulated as special regime or not.

Second, Portugal does not include nuclear energy in its current mix. Therefore, building a plant of this kind would be a first of a kind project, which could result in increased cost and risks of overrunning the initial budget.

All these factors have to be properly evaluated in order to mitigate their impact on the project, since an investment with lower perceived risks, is also more likely to attract more investors, and/or to lower the cost of collection of capital.

4.2 Parameters Estimation

The following chapters will describe the methodology used to determine the parameters for the model describing the Portuguese scenarios. Although many of these values are just proxy, the framework provided is valid in case of further development of the analyses.

4.2.1 Price Conversion

The MIT model uses parameters which are expressed in 2002 USD currency. The costs and revenues in the Portuguese model are expressed in 2010 EUR*. Furthermore, the new model uses for fuel and overnight costs values taken from the 2008 update of the “Future of Nuclear Power” paper, which are expressed in 2007 USD. In order to uniform all of the data the voices are converted using the following procedure:

- Adjustment with inflation rates up to 2010

* The year is intended until May 2010, as also specified on the tables and figures

- Conversion using average EUR/USD currency exchange rate for 2010

According to the data in table 4.1 below, we obtain the following conversion rates:

- 1 $\$_{2002}$ = 0.868 $€_{2009}$
- 1 $\$_{2008}$ = 0.767 $€_{2009}$

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010*
EUR/USD Rate	1.06	0.89	0.80	0.80	0.80	0.73	0.68	0.72	0.74
Inflation Rate	1.6%	2.3%	2.7%	3.4%	3.2%	2.9%	3.8%	-0.4%	0.2%

*as of May 2010

Table 4.1: Yearly Average Inflation Rate for United States and EUR/USD Exchange Rate

(Source: www.global-rates.com, 2010)

It is important to notice that comparing project with different currencies and in different years may be a risky procedure, because currency exchange rates may not reflect accurately the relative costs of good and services which are not traded internationally. Rapid swings in the exchange rate may in fact obscure real costs.

4.2.2 Inflation Rate

In the model, the prices are nominal, so they have to be adjusted according to an inflation rate. The model uses one base parameter for most of the prices and costs, and corrects by a real escalation factor the costs for fuel and O&M costs. In order to replicate these parameters for the Portuguese case, three different inflation rates will be used; these rates are taken from the OECD classification: general inflation, inflation for energy products, and inflation for non-food, non-energy products. Since no reliable forecast about the inflation rate can be found for such a long period, historical data is used to make the estimation: the data set used for reference is the Consumer Price Index (CPI) (Source: OECD). US data is used as a basis for benchmark.

Fig. 6: Evolution of Inflation Rates in Portugal

(Source: OECD)

By looking at the graph in figure 6 above, it is immediate to notice the difference between the time series describing the evolution of energy prices, which shows high volatility, and the other two, which seem to settle on a more stable trend. The average of the inflation rates during this period of low volatility, which goes from 1996 to 2009, is used as a basis for the forecast. The results are illustrated in table 4.2 below:

Product Basket	Mean	Std. Dev.
General **(I)**	2.63%	1.15%
Energy **(II)**	3.34%	4.17%
No-Food, No-Energy **(III)**	2.73%	0.88%

Table 4.2: Average Inflation Values for Portugal, between 1996 and 2009

The parameters for the Portuguese case are obtained from the previous results, and are outlined in the following table (values are rounded to the first decimal place before doing the calculations):

	New Model	Original Model
Inflation Rate **(I)**	2.60%	3.00%
Real fuel Escalation Rate **(II) - (I)**	0.70%	0.50%
O&M Escalation Rate **(III) - (I)**	0.10%	1.00%

Table 4.3: Average Annual Inflation Rates (forecasts produced by the author for the period 2010 - 2050)

4.2.3 Interest Rate

The debt interest rate depends on many factors, such as the total amount of capital borrowed, the risk associated to the loan (solvability of the borrower and risk associated to the investment). In the past most of the NPP investments were developed by public or regulated private vertically integrated utilities monopolies (MIT, 2003). This model of industrial organisation is more likely to be present in a regulated market. Nowadays many countries, including Portugal, are moving away from this model, in order to move towards a structures that involves competitive independent generation power plant investors.

Since no one in Portugal has ever done an investment of this kind, it was decided to analyse a company that operates in a similar market: EDP Renováveis, S.A. (EDPR). EDPR is a company, incorporated in the end of 2007 from the integration of EDP's renewable assets in Europe and the US. Although it is not likely that EDPR itself would make the investment (renewable energy companies are among the main opponents to nuclear energy), it presents features which make it a suitable candidate to do an investment of this kind: medium-high capitalisation, operating in the energy sector, Portugal as main target of interest. Table 4.4 below outlines its main financial indicators:

Table 4.4 EDPR Main Financial Indicators

(Source: EDPR, Prices in Mln €)

	2009	2008
Market Value (Equity)	5784	4364
Net Income (for equity holders)	114	104
ROE	19.71%	23.83%
Net Debt	2134	1069
Total Liabilities	5966	4220
Debt fraction	52.82%	44.80%

**Debt is intended as the total of the liabilities, not only the net debt.*

In 2009, EDPR's liabilities amount to 53% of the total assets. It can be assumed that the company will make an investment which matches its balance sheet structure, so the same debt to equity ratio can be used for the model. Its average cost of debt is 4.8% in 2009. In order to use this value as a proxy for the interest rate of the debt of the investment, it needs to be increased by a risk premium, since nuclear investments are perceived as riskier by the investors, if compared with renewable energies projects. Therefore, it can be assumed that 6% interest rate is a reasonable proxy for the model.

4.2.4 Technical Parameters

All the parameters concerning the technical aspect of the nuclear plant, are the most difficult to handle and estimate; this is due mainly the fact that very few nuclear projects have been commissioned in the past decades, and that this would be a FOAK project in Portugal. The most recent project concerning nuclear plants proposed in Portugal has been the one by Monteiro de Barros (2005), which proposes the installation of a 1.6 GWe reactor. This value will be used instead of the 1 GWe value from MIT. Since no further evaluation can be made, the parameters for operational costs and other technical specifications of the plant remain the same as the MIT model. The definition of these features requires detailed information about the projects and it goes beyond the scope of this work. As it will be outlined in the analysis in chapter 5.2, the uncertainty of these parameters does not sensibly affect the final cost of electricity, therefore it can be assumed that the estimations done in the MIT model are reasonable.

4.2.5 Operational and Overnight Costs

Operational and overnight costs, for the same reasons as the technical parameters, did not undergo major changes. The only adjustment made are currency exchange and inflation rate. The methodology for the conversion rate has already been explained in chapter 4.2.1. Overnight and Fuel costs are estimated not from the original MIT paper (2004), but from its update (2008), which shows an estimation of costs in 2007 USD. The results are summarised in table 4.5 below:

Parameter	**MIT Model [2002 USD]**	**Our Estimation [2010 EUR]**
Decommissioning Cost **[million €\$]**	350	314
Fixed O&M **[€\$/kWe/year]**	63	57
Variable O&M **[mills/kWh]**	0.47	0.42
Parameter	**MIT Model [2008 USD]**	**Our Estimation [2010 EUR]**
Overnight Cost	4000	3068
Fuel Costs **[€\$/mmBTU]**	0.67	0.51

Table 4.5: Estimations for Operational and Overnight Costs

4.2.6 Return to the Investors

The Capital Asset Price Model (CAPM) is used to estimate the cost of capital. This model evaluates the expected rate of return of an asset r_e, given the risk-free rate of return r_f, the expected average return of the market r_m, and the beta coefficient β, which is an indicator of the correlation between the return of the asset and the market. The formula is shown below:

$$E(r_e)=r_f+\beta\cdot(E(r_m)-r_f) \quad \textbf{(18)}$$

the difference between the market return and the risk-free rate is also known as the average risk premium required by the investors.

This model can be used to evaluate different kind of assets, such as stocks or projects. In the previous chapter, we assumed that it would be likely for a company like EDPR to make this kind of investment. Therefore, the expected return for this company, calculated with the CAPM, should be a reasonable proxy of the return required by the investors in the nuclear power plant project.

The parameters are calculated as follows:

- **Risk free rate:** a study by Harris (2004) shows that the the risk free rate is usually chosen between the 90 days treasury bills, and treasury bonds with maturity in 10 years or longer. 70% of the interviewed corporations and financial advisors prefer using long-term bond yields. For this reason, we use as the risk free rate the arithmetic average of the monthly average return for 10 years Portuguese treasury bonds, from January 2007 to may 2010. Their performance over the years is shown in figure 7 below:

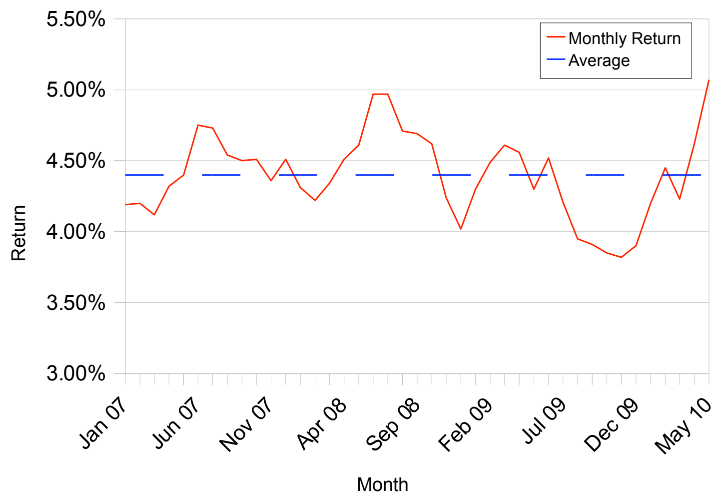


Fig. 7: Average Monthly Return for 10-years Portuguese Treasury Bonds, from January 2007 to May 2010

(source: Trading Economics, www.tradingeconomics.com)

  The dashed line shows the mean value for the graph, which is set to 4.4%. This value is used for the risk-free rate in the model.

- **Beta:** the Beta value, according to finance theory, has to be forward looking, in order to reflect investors' uncertainty about future cash flows to equity. But since forward values are unobservable, proxies have to be used, mainly by historical data. The beta value in this model is taken from Bloomberg (source: www.bloomberg.com). It is calculated using a 24 month historical regression of returns by EDPR against PSI 20, the main index for Portuguese equities, and has a value of 0.978.
- **Risk Premium:** as value for the risk premium we chose to use the Portuguese Equity Risk

Premium. Alpalhão and Alves (2004) estimate a value between 6 and 7%. A more recent estimation has also been done by Damodaran (2010). He calculates a country risk premium of 0.9% above the general risk premium of countries with mature economies, which is set to 4.5%. This gives a total premium of 5.4%.

Table 4.6 below summarises the results:

Parameter	Value
Risk Free Rate:	4.40%
Expected Risk Premium:	5.40%
Beta:	0.978
Estimated Return:	9.70%

Table 4.6: Estimation for CAPM Parameters

It is important to notice that this parameter is the one the most influences the levelised cost of electricity (See section 5.2); its estimation then is the one that requires the most attention in the event of an investment.

4.2.7 Taxation

Portugal corporate income tax rate added up to 25% in 2009 (source: KPMG, 2009). In addition to this rate, municipalities add a surcharge, called *derrama*, which varies from 0 to 1.5%, which is deducted from taxable profit. Due to the uncertainty on location of the construction site of the power plant, an average value of 1% is used. This sets the total corporate tax to 26%, lower than the 35% set for the MIT model.

4.2.8 Depreciation

The depreciation schedule used in the MIT model, called Modified Accelerated Cost Recovery System, is used mainly in the United States. According to the Inland Revenue Department (*Direcção-Geral dos Impostos*), the depreciation of an asset in Portugal is done through constant quotes. The number of years during which an asset is depreciated, hence the depreciation rate, depends on the type of asset. Due to the absence of regulation concerning nuclear power plants, an hypothetical depreciation schedule has to be derived from the existing regulation (afterward, a sensitivity analysis on the parameter will performed to check the validity of the estimation):

Code		Years	Rate [%]
	Specific Rates		
1225	Hydraulic Fixed Works	30	3.33
1235	Thermoelectric plants equipment	12	8.33
	Generic Rates		
2010	Residential fixed assets	50	2
2015	Commercial fixed assets	50	2
2020	Industrial fixed assets	20	5

Table 4.7: Depreciation Schedule for Portuguese Assets

(Source: IRC Code)

We will use as estimation a value of 20 years, since it is the term used for a general industrial asset. Given the absence of regulation, it can be considered a safe approach. Other fixed assets tough are depreciated with a munch longer schedule (up to 50 years). This suggests the need to run a sensitivity analysis on this parameter in order to evaluate the necessity for further analysis.

4.3 Results

This chapters summarises what said in chapter 4.2; the table below contains all the parameters that will be used in the Portuguese model for the calculation of the levelised cost of electricity (all the costs are expressed in 2010 EUR):

Variable	**Symbol**	**Value**
Inflation Rate	i	2.60%
Interest Rate	r_d	6.00%
Expected return to equity investors	r_e	9.70%
Debt to Equity ratio	D/E	1.22
Tax rate	τ	26.00%
Debt term **[years]**	N_d	10
Net capacity **[MWe]**	L	1600
Capacity factor	Φ	85.00%
Plant Life **[years]**	N	40
Heat Rate **[BTU/kWh]**	HR	10400
Overnight Costs **[€/kWe]**	C_0	3068
Construction Period **[years]**	N_d	5
Depreciation Schedule **[years]**		20
Depreciation method		Linear
Decommissioning cost **[million €]**	C_{Decom}	314
Incremental Capital cost **[€/kWe/yr.]**	C_{Incr}	18
Fuel costs **[€/mmBTU]**	C_{Fuel}	0.51
Real fuel escalation	e_f	0.70%
Nuclear waste fee **[mill/kWh]**	C_{Waste}	0.9
Fixed O&M **[€/kWe/yr]**	C_{OMf}	57
Variable O&M **[mills/kWh]**	C_{OMv}	0.42
O&M Escalation Rate	$e_{O\&M}$	0.1%

Table 4.8: Parameters Used in the Portuguese Model

The model returns for these values a Levelised Cost of Electricity of 5.75 cents/kWh.

5 Model Evaluation and Results Analysis

The following sections analyse the cost of electricity obtained with the model described in chapter 4: section 5.1.1 makes a comparison between the cost obtained in the new model and the one obtained in the analysis done by MIT (section 5.1.1), then it analyses whether it can be competitive with electricity currently purchased in the free market (section 5.1.2) and in the regulated market (chapter 5.1.3). In section 5.2 a sensitivity analysis on the main parameters is performed to check the sensitivity of the LCOE to a variation of their values; a reversed approach is used in section 5.2.1 in order to find the swings necessary to each parameter in order to lower the price of electricity to the threshold set by the Portuguese government for energy produced in special regime. In section 5.3 scenario analysis is used in order to study what could happen in case of simultaneous changes in the parameters of the model. The last section summarises what has been told in the previous ones.

5.1 Results Comparison

5.1.1 Comparison with MIT Model

The MIT model, if translated to nowadays price (first adjusting the cost according to the US energy inflation rate, then converting it using average 2010 USD/EUR exchange rate), gives a LCOE of 7.68 cent/kWh (in 2010 euros). This price is a little higher than the one estimated for the Portuguese case. As it will be outlined in the sensitivity analysis in section 5.2, the LCOE calculated in the model is highly influenced by the cost of capital, given the capital-intensity nature of this kind of investment. Table 5.1 below shows that the average cost of capital for the Portuguese (6.9%) model is much lower than the original MIT one (11.5%). The lower costs of capital for our model then balances the higher costs.

Table 5.1 Cost Comparison

	MIT Model	Portuguese Model
LCOE [2010 cent/kWh]	7.68	5.75
Average Cost of Capital	11.50%	6.90%
Average Cost of Capital (with fiscal shield)	9.98%	6.04%
Overnight costs [2010 €/kWe]	1800	3068
1st year Operating expenses [2010 million €]	131	214

It is important to note that this analysis aims to compare how the parameters in the two models affect the final result; it does not intend to analyse which investment is better, since we compare nuclear power plants in different countries and in different years. An evaluation of that kind would require much data to take into account and goes beyond the scope of this work.

5.1.2 Comparison with Market Price

As already outlined in chapter 2.5.1.1, the electricity in Portugal can be sold or bought in a deregulated market. Thus the price that can be used for comparison is the purchase price on this market, the Iberian Electricity Market (Mercado Ibérico de Electricidade, MiBEL). In this market the electricity is sold in the form of future or spot contracts. For this case we will focus on future contracts. There are two basic types of MIBEL futures contracts: one has a physical delivery and the other foresees a purely financial settlement at maturity, with the peculiarity that both types of contracts benefit from a common order book. The remaining characteristics are common to both contracts:

- Differentiation between “base load” and “peak load” contracts
- Contract unit: 1 MW * contract number of hours
- Quotation and tick: in euros/MWh, with a 0.01 euros/MWh tick
- Delivery periods: weeks, months, quarters and years

The spot reference price is used for settlement at maturity for both types of contracts: monetary value of the "SPEL base" index, which represents an average price of electric energy in the Spanish zone, based on the values seen on the cash market managed by OMEL.

The managing entity for the MiBEL derivative market is OMIP. Its role is to ensure the management of the MIBEL derivatives market, jointly with OMIClear - (Energy Markets Clearing Company) Sociedade de Compensação de Mercados de Energia, S.G.C.C.C.C., S.A., a company constituted and totally owned by OMIP, which executes the role of Clearing House and Central Counter-party of operations carried out on the market.

In order to produce reliable and solid references for the Iberian electricity market, to enable the trading of derivatives products, OMIP calculates and diffuses electricity indexes, which will represent the time evolution of that underlying. The indexes diffused concern the main patterns of trading, and are divided in base-load and peak-load indexes, and geographically for Portugal (PTEL) and Spain (SPEL).

Our reference for price comparison is the PTEL Index for base-load generation, since nuclear energy generation is suitable for this segment of the market. Figure 8 below shows the evolution of the price of the index since 2009:

Fig. 8: Daily Settlement Price and Yearly Average Price for PTEL Base Index in 2009

(Source: OMIP)

The average price for the PTEL Base Index in this period is 40.87 €/MWh, which equals 4.09 cent/kWh, to match the model's units. This value is the value that will be used for comparison for the model as market price. This value is considerably lower than the LCOE for nuclear energy estimated with the model. With a cost of 5.75 cent/kWh (about 40% higher), nuclear cannot compete in this market.

5.1.3 Comparison with Renewable Energies

Due to the high commitment of Portugal in renewable energy, it is interesting to compare the price of nuclear energy with this kind of generation; even though they are not used still for base load generation, they are also a carbon-free alternative to fossil fuel generation, and they will probably be one of the main rival to the development of nuclear energy.

An estimation for the generation costs can be found in the regulatory decree by ERSE (2010), the regulatory agency for energy in Portugal. Electricity from renewable sources, in fact, is produced under what is called “special regime generation” (Produção em Regime Especial). According to regulation, 100% of this energy has to be purchased by a last resort supplier; this role is undertaken by EDP Serviço Universal (EDP S.U.), which is a company within the EDP Group. The purchase value of electricity in special regime is set each year by ERSE. The price for 2010 was set to 50€/MWh. But this value is not fixed; each year in fact, a new threshold is set (for simplicity reason we will run our analyses only on the 2010 value). In 2010 the compensation amounted to 487 million €, for the purchase of 11443 GWh of electricity from renewable energies. The average purchasing price are listed in table 5.2 below:

Table 5.2 Average Purchasing Price for Electricity from Renewable Sources in 2010

(Source: ERSE)

	Average Purchasing Price [€/MWh]	GWh
Wind	91.07	7794
Hydroelectric	88.70	885
Biogas	111.20	58
Biomass	113.40	590
Photovoltaic	344.77	83
Thermal	83.60	1588
RSU	80.90	445
Special Regime Production	***92.55***	***11443***

The average purchasing price is 9.23 cents/kWh. The LCOE calculated with our model is almost 40% lower than this, and still more convenient than any of the alternatives taken individually. Since electricity produced this way is made competitive thanks to the help of the state, an investment in nuclear energy would be strongly influenced by the position taken by the national government on the issue.

5.2 Sensitivity Analysis

A sensitivity analysis is generally used to check the robustness of a result to the variation of its parameters. In the case studied in this paper, the objective of the analysis will be to identify which parameters affect the most the final cost of electricity. These parameters, in fact, are the ones that will require the most attention when being assessed, since an error in their estimation will impact more the final results.

Two tools in particular will be used to perform the evaluation: a tornado diagram and a spider graph. A tornado diagram shows the parameters affect the final output of the model (in this case, the LCOE), when swinging from a minimum to a maximum hypothetical value. This tool is used for preliminary analysis, since it does not consider correlation or statistical profiles of the parameters.

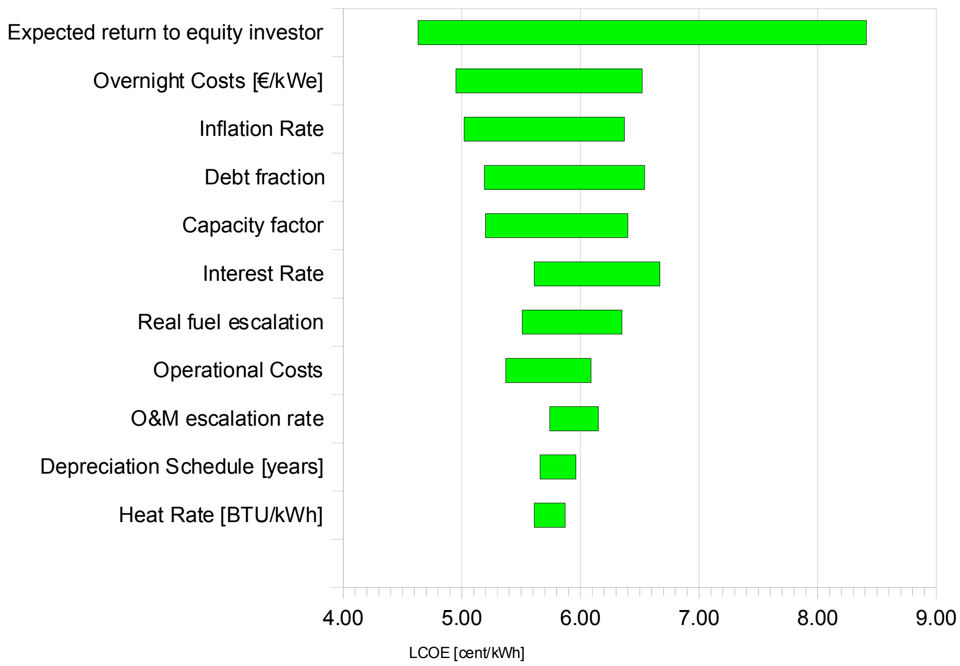
In the following paragraph we will outline the methodology used for estimating the swing for each parameter. A standard swing from -20% to +20% is used for the parameters for which we do not have sufficient information. This includes operational and overnight costs, heat rate and plant capacity. Operational costs are evaluated in cluster all together, due to their lower individual impact on the cost. The other swings are estimated as described below:

- **Inflation Rates**: the swings are given by the statistical standard deviation of the inflation rates obtained in chapter 4.2.3, rounded to the first decimal place.

- **Interest Rate:** the minimum swing corresponds to the value obtained for the Finnish plant Olkiluoto 3 (see Finion and Roques, 2008), which is until now the lowest possible rate obtained for an investment of this kind. As a top value, we used the value for the original MIT model.
- **Return to Equity Investors**: this value also ranges from the value in the original MIT model, as the upper bound, and a standard 20% reduction as a lower bound.
- **Debt to equity ratio**: it ranges from to 5/95 to 95/5, in order to simulate an investment financed mostly by debt or mostly by equity.
- **Depreciation schedule**: it ranges from 10 years, as the original MIT model, and 50 years, which is the longest time range for building depreciation in Portugal.

The results are shown in figure 9 below:

Fig. 9: Tornado Diagram for parameters affecting LCOE



The initial cost of the investment (which is a function of overnight costs, interest rate and expected return to equity investors) is the one that most affects the final cost of electricity; the parameter which presents the largest absolute wing is the expected return to equity investors, which is more than 3 cents/kWh. Operational and fuel costs do not affect the price sensibly, which also proves what has been said before about nuclear energy: expensive initial investment, but low marginal costs afterward. The tornado diagram is a good tool for preliminary analysis, but alone does not provide sufficient information, since minimum and maximum swing for many of the parameters were not known. This is why together with this diagram we present another tool, which is called "spider graph". This graph compares the relative, not the absolute, swings of each parameter, with the relative swing in the output. Since it is a relative term, less error is introduced by not knowing the swing range of the parameters. The results are shown in figure (for easiness of reading, only the most important parameters were reported in the graph):

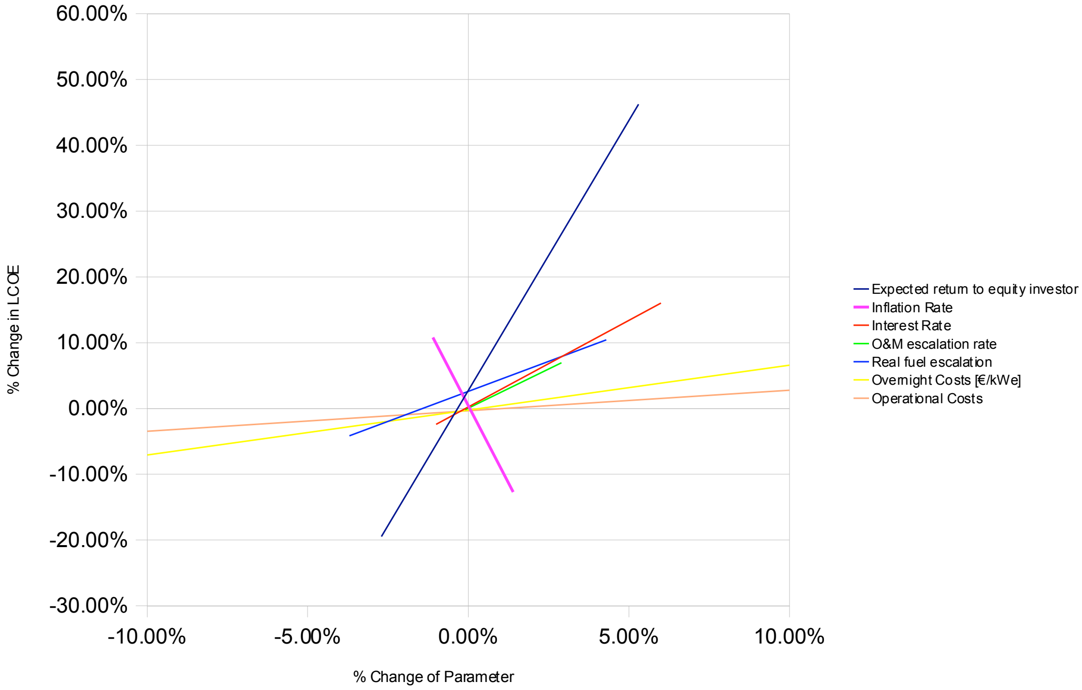


Fig. 10: Spider Graph

The x-axis represents the relative swing in the input parameter, while the y-axis the relative swing in the output, in this case the LCOE. The steepness of the lines represents the sensitivity of the output to the relative input parameter. As also outlined in the previous diagram, the expected return to the investors is still the variable that mostly affects the final cost of electricity, followed by inflation and interest rates. For each percentage point that this parameters increases in fact, the cost of electricity has a raise of about 8%.

It is important to notice that inflation rate, despite its significance on the graph, can be excluded from the list of critical parameters; this kind of graph, in fact, only shows how much the output changes, given a variation in its inputs. In order to evaluate risk, together with the impact that this risk produces, we have to consider the probability of it happening. Inflation in fact has a very low volatility and it is easier to predict than the other parameters, thus there is less risk of having very high or very low swings.

In conclusion, these graphs prove that the average cost of capital is the most influencing parameter in the model; in particular the cost of equity, which is represented by the return to the investors, presents the largest absolute and relative swings. This analysis outlines the impact of the uncertainty of the parameters in the model. In order to perform a more complete risk evaluation, we would need to keep in consideration also the probability distribution of the uncertainties, and this goes beyond the scope of this paper.

5.2.1 Optimisation of the Model

Another use that can be done of the sensitivity analysis tools is checking what is the needed change in a parameter to produced a desired output. As already mentioned in chapter 5.1.3 the Portuguese regulatory agency for energy set a cost of 50 €/MWh for energy produced in special regime, based on production forecasts. We can assume this price to be the optimisation target of our analysis. From the tornado diagram we can already see that the only parameter that alone can lower the price down to the target value is the expected return to equity investors. As for the other parameters we either have to set higher swings or, like in the case of operational costs, we have to lower them together. This is why in this case we studied the impact of lowering the total cost of capital, the initial cost of the investment, and overall costs (investment and operational costs). Operational costs are not evaluated individually because their impact on the cost is not so significant to reach the target of 50€/MWh individually. In table 5.3 below, we calculated the necessary swing to each of these parameters in order to achieve that result:

Table 5.3 Optimisation of LCOE

Parameter	Target	Swing Required
Average Cost of capital	6.50%	-1.10%
Overnight & Operational Costs		-13%
Overnight Costs Alone	2500 €/kWe	-19.00%

We can immediately notice that in order to meet target costs imposed by ERSE, the plant needs to get funds at an average cost of capital of 5.4%, which is a very convenient financing condition: so far, only the new Finnish reactor Olkiluoto III was financed with an overall cost of capital of 5% (see Finion and Roques, 2008). This rate is especially difficult to obtain, especially now that Moody decided to lower Portugal's rating down by two notches, from A1 to aa2 (source*:* RTTnews); this increases the average cost required by banks for borrowing funds. If we take a look at the costs instead, the initial investment should be lowered down by 19%, figure that is reduced if this reduction is mirrored also in the operational costs. As previously stated, these swing are only theoretical, but they give an idea on which parameters presents the widest range for improvement; furthermore, this analysis could be used to set target costs for the installation of other plants, since it can outline the required reductions in costs in order to achieve competitive prices in the generation of electricity.

5.3 Scenario Analysis

In section 5.2.1 we analysed how the main parameters of the model should be changed in order to reach the target cost of electricity of 50€/MWh. The parameter where analysed either alone, or in clusters, that were changed uniformly. This feature makes the analysis very easy to perform, but at the same time it fails to give complete information, since parameters are usually correlated to each other and/or they may change in different directions from what they were originally planned.

A scenario analysis can be used to evaluate the impact of different parameters when their changes occur at the same time, and it can consider both endogenous and exogenous variables; for our model, this is the approach that has been used, to perform the analysis:

- **Choice of the parameters to evaluate**: these parameters are chosen based on the previous analysis. We have chosen to analyse the impact of the average cost of capital, overall costs, and fuel costs, represented by the "real fuel escalation rate parameter"
- **Creating sub-sets for each parameter**: for each variable, we set a value for "best case", "worst case" and "as-is" scenario. The values can be extrapolated from the sensitivity analysis, or estimated using a similar approach, and are reported in the following table:

Table 5.4 Parameters Used in Scenario Analysis

Parameter	Worst Case	As-Is	Best Case
Average Cost of Capital	11.5% (MIT Model)	7.67%	5% (Finnish Case) (4/6.3)
Overall Costs	10.00%	0	-10.00%
Fuel escalation rate	9%	3.3%	0.50%

- **Combining the sub-sets**: all the sub-sets are combined in order to obtain 27 possible scenarios to analyse. The number of possible scenario increases rapidly if more parameters or more sub-sets are added. It is thus very important to find the balance between completeness of the analysis and the easiness of reading.
- **Plotting results**: once all the scenarios are evaluated they can be plotted on a tree-graph: the results are shown in figure 11 below:

Fig. 11: Scenario Analysis

Overall Costs	Fuel Costs	LCOE (cent/kWh)
B	B	3.59
	A	3.82
	W	4.48
A	B	3.90
	A	4.17
	W	5.03
W	B	4.20
	A	4.54
	W	5.57
B	B	3.58
	A	5.37
	W	5.86
A	B	5.51
	A	5.75
	W	6.35
W	B	5.82
	A	6.11
	W	6.82
B	B	8.26
	A	8.41
	W	8.71
A	B	8.61
	A	8.74
	W	9.13
W	B	8.90
	A	9.12
	W	9.58

B = Best case Scenario
W = Worst Case Scenario
A = As-Is Scenario

The analysis shows once again the importance of financing conditions for a nuclear plant investment. In fact, almost all the scenarios that present a competitive LCOE of 5 cents/kWh or less (in green in the table), have in common the best case scenario for the cost of capital.

In order to use this analysis as a decision support tool, for forecasting purposes, we need to assess probability distributions for each of the subsets. In this way it is possible to calculate a scenario-weighted expected cost, which considers also the uncertainty in the estimations. For a preliminary analysis, we can assume each of the scenarios to be equiprobable, since we do not have any other information; in this case, having 9 probable scenarios out of 27 means a 33% probability of having a competitive costs. Once again, this value has to be used with caution, since its prediction it is heavily dependent on the model and on the hypothesis on which it was built.

5.4 Overview of the Results

With a total LCOE of 5.75 €/kWh, nuclear does not seem not to be a competitive option in Portugal, if compared with both market price and regulated renewable energy price (see table 5.5 below); in fact, the estimated costs for nuclear energy is 40% lower than the prediction set by ERSE for the production in 2010.

Table 5.5 Benchmark of Electricity Costs in Portugal

	Fare [cents/kWh]	Source
Nuclear	5.75	*MIT*
Portuguese Market	4.09	*MIBEL*
Special Regime (ERSE Prediction)	5.00	*ERSE*
Special Regime	9.23	*ERSE*

The parameter which presents the largest absolute swing (and therefore is the most critical for the robustness of the estimation), is the cost of the equity capital: the analyses done in chapter 5.2, in fact, show that for each percentage point of change in the cost of capital, the LCOE changes by about 8%.

If costs objective had to be specified, in order to reach the same costs as renewable energy with subsides, the costs of financing should be either lowered to 5.4%, or the total costs of the investment (overnight and operational) should be lowered on average by 13%.

If we model the possible combination of three different scenarios, in which three main cost drivers (Overall costs, cost of financing and escalation rate of fuel prices) can have a worst case, best case, and most likely outcome, the LCOE is below or approximately equal to the regulated cost.

6 Conclusions

The model implemented in this thesis shows that in financial terms, nuclear energy still is not a viable option in Portugal. The analysis has shown that the current generation alternatives have more competitive prices so far. However, this model alone cannot be used as a decision tool: in fact, it concerns merely the financial analysis of a possible project of a nuclear reactor. Despite that, the relevance of the model has been demonstrated by allowing to calculate what would be the cost of producing electricity in a hypothetical nuclear power plant in comparison to the current generation alternatives in Portugal. Furthermore, it also allowed to check how robust these results are to uncertainties in the estimation of its parameters. In order to make an educated decision, politicians and investors should investigate also on the other “non-economical” costs involved in a project of this kind, such as environmental and costs; possible problem that can be addressed are:

- How nuclear could fit in the electricity grid?
- How would electricity produced through nuclear energy be regulated (will it be sold and purchased on the free market, or through a last resort supplier like special regime generation?)
- How competitive will renewable energies be in the nearby future? Is it possible to have both?
- How long will the fossil fuels supplies last?

Within the next few years, nuclear does not seem to be a viable alternative for Portugal. In the future though, once the current thermal plants will finish their life cycle, and carbon-free solution will have to be implemented, nuclear will probably be taken in consideration again.

We do not intend to answer all these questions through our model; its scope is to be used as decision support tool, which will help defining the financial aspect related to this kind of decision.

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Appendix 1 – Base Case Model

Appendix 2 – Portuguese Case Model

Appendix 3 – PBEL Prices

Appendix 1 – Base Case Model

Appendix 1 - Base Case Model

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Electricity price (cents/kWh)		6.92	7.13	7.34	7.56	7.79	8.02	8.26	8.51	8.77	9.03	9.3	9.58	9.87
Revenue ($million)		**515**	**531**	**547**	**563**	**580**	**597**	**615**	**634**	**653**	**672**	**692**	**713**	**735**
Operating expenses														
Fuel Cost		38	39	40	42	43	45	46	48	50	51	53	55	57
Waste Fee		8	8	8	9	9	9	9	10	10	11	11	11	12
Fixed O&M		66	68	71	74	77	80	83	86	90	93	97	101	105
Variable O&M		4	4	4	4	4	4	5	5	5	5	5	6	6
Decommissioning		9	9	9	9	9	9	9	9	9	9	9	9	9
Incremental Cap.		21	21	22	23	23	24	25	25	26	27	28	29	29
(I) Operating Income		***369***	***382***	***393***	***402***	***415***	***426***	***438***	***451***	***463***	***476***	***489***	***502***	***517***
Depreciation (tax)		92	174	157	141	127	114	108	108	108	108	108	108	108
Interest Payments		92	86	79	72	64	55	46	35	25	13			
Debt Principal Repayment		80	86	93	100	108	117	126	137	147	159			
Taxable Income		185	122	157	189	224	257	284	308	330	355	381	394	409
Income tax Payment		70	46	60	72	85	98	108	117	125	135	145	150	155
Net Income		35	-10	4	17	31	42	50	54	58	61	236	244	254
Cash Flow	***-1402.46***	***127***	***164***	***161***	***158***	***158***	***156***	***158***	***162***	***166***	***169***	***344***	***352***	***362***
IRR	15.01%													
LCOE (USD 2003)	6.92													
LCOE (EUR 2010)	7.68													
NPV	**-1402.46**	**110.43**	**124.01**	**105.86**	**90.34**	**78.55**	**67.44**	**59.4**	**52.96**	**47.19**	**41.77**	**73.94**	**65.79**	**58.84**

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10.17	10.48	10.79	11.11	11.44	11.78	12.13	12.49	12.86	13.25	13.65	14.06	14.48	14.91	15.36	15.82	16.29
757	**780**	**803**	**827**	**852**	**877**	**903**	**930**	**958**	**987**	**1016**	**1047**	**1078**	**1110**	**1144**	**1178**	**1213**
59	61	63	65	68	70	72	75	78	80	83	86	89	92	95	99	102
12	12	13	13	14	14	15	15	16	16	17	18	18	19	20	20	21
109	113	118	123	128	133	138	144	149	155	161	168	175	182	189	196	204
6	6	7	7	7	7	8	8	8	9	9	9	10	10	10	11	11
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
30	31	32	33	34	35	36	37	38	39	41	42	43	44	46	47	49
532	***548***	***561***	***577***	***592***	***609***	***625***	***642***	***660***	***679***	***696***	***715***	***734***	***754***	***775***	***796***	***817***
108	108															
424	440	561	577	592	609	625	642	660	679	696	715	734	754	775	796	817
161	167	213	219	225	231	238	244	251	258	264	272	279	287	295	302	310
263	273	348	358	367	378	387	398	409	421	432	443	455	467	480	494	507
371	***381***	***348***	***358***	***367***	***378***	***387***	***398***	***409***	***421***	***432***	***443***	***455***	***467***	***480***	***494***	***507***
52.43	**46.82**	**37.19**	**33.27**	**29.66**	**26.56**	**23.65**	**21.15**	**18.9**	**16.91**	**15.09**	**13.46**	**12.02**	**10.73**	**9.59**	**8.58**	**7.66**

31	32	33	34	35	36	37	38	39	40
16.78	17.28	17.8	18.33	18.88	19.45	20.03	20.63	21.25	21.89
1249	**1287**	**1325**	**1365**	**1406**	**1448**	**1491**	**1536**	**1582**	**1630**
106	109	113	117	121	126	130	135	139	144
22	22	23	24	25	26	27	28	28	29
213	221	230	239	249	259	269	280	291	302
12	12	13	13	14	14	15	16	16	17
9	9	9	9	9	9	9	9	9	9
50	52	53	55	56	58	60	61	63	65
837	***862***	***884***	***908***	***932***	***956***	***981***	***1007***	***1036***	***1064***
837	862	884	908	932	956	981	1007	1036	1064
318	328	336	345	354	363	373	383	394	404
519	534	548	563	578	593	608	624	642	660
519	***534***	***548***	***563***	***578***	***593***	***608***	***624***	***642***	***660***
6.82	**6.1**	**5.44**	**4.86**	**4.34**	**3.87**	**3.45**	**3.08**	**2.76**	**2.46**

Appendix 2 – Portuguese Case Model

Appendix 2 - Portuguese Case Model

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Electricity price (cents/kWh)		6.1	6.26	6.42	6.59	6.76	6.94	7.12	7.31	7.5	7.7	7.9	8.11	8.32
Revenue ($million)		**727**	**746**	**765**	**785**	**805**	**827**	**848**	**871**	**894**	**917**	**941**	**966**	**991**
Operating expenses														
Fuel Cost		78	81	83	86	89	92	95	98	101	105	108	112	115
Waste Fee		13	14	14	15	15	16	16	17	17	18	18	19	20
Fixed O&M		112	115	118	121	124	128	131	135	138	142	146	150	154
Variable O&M		6	6	6	7	7	7	7	7	8	8	8	8	8
Decommissioning		9	9	9	9	9	9	9	9	9	9	9	9	9
Incremental Cap.		36	37	38	39	40	41	42	43	44	46	47	48	49
(I) Operating Income		***473***	***484***	***497***	***508***	***521***	***534***	***548***	***562***	***577***	***589***	***605***	***620***	***636***
Depreciation (tax)		227	227	227	227	227	227	227	227	227	227	227	227	227
Interest Payments		179	165	151	136	119	102	84	65	45	23			
Debt Principal Repayment		226	240	254	269	285	302	321	340	360	382			
Taxable Income		67	92	119	145	175	205	237	270	305	339	378	393	409
Income tax Payment		17	24	31	38	46	53	62	70	79	88	98	102	106
Net Income		-176	-172	-166	-162	-156	-150	-146	-140	-134	-131	280	291	303
Cash Flow	***-2707.05***	***51***	***55***	***61***	***65***	***71***	***77***	***81***	***87***	***93***	***96***	***507***	***518***	***530***
IRR	9.7%													
Electricity price (EUR 2010)	6.100													
NPV	-2707.05	46.49	45.7	46.21	44.88	44.69	44.18	42.37	41.48	40.42	38.04	183.12	170.55	159.07

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
8.54	8.76	8.99	9.22	9.46	9.71	9.96	10.22	10.49	10.76	11.04	11.33	11.62	11.92	12.23	12.55	12.88
1017	**1044**	**1071**	**1098**	**1127**	**1157**	**1187**	**1218**	**1250**	**1282**	**1315**	**1350**	**1384**	**1420**	**1457**	**1495**	**1534**
119	123	127	131	136	140	145	149	154	159	165	170	176	182	188	194	200
20	21	22	22	23	24	25	25	26	27	28	29	30	31	32	33	34
158	162	167	171	176	180	185	190	196	201	206	212	218	223	229	236	242
9	9	9	9	10	10	10	10	11	11	11	12	12	12	13	13	13
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
50	52	53	54	56	57	59	60	62	64	65	67	69	70	72	74	76
652	***668***	***684***	***702***	***717***	***737***	***754***	***775***	***792***	***811***	***831***	***851***	***870***	***893***	***914***	***936***	***960***
227	227	227	227	227	227	227	0	0	0	0	0	0	0	0	0	0
425	441	457	475	490	510	527	775	792	811	831	851	870	893	914	936	960
111	115	119	124	127	133	137	202	206	211	216	221	226	232	238	243	250
314	326	338	351	363	377	390	573	586	600	615	630	644	661	676	693	710
541	***553***	***565***	***578***	***590***	***604***	***617***	***573***	***586***	***600***	***615***	***630***	***644***	***661***	***676***	***693***	***710***
148.01	137.92	128.45	119.79	111.46	104.02	96.86	82	76.45	71.35	66.67	62.26	58.01	54.28	50.6	47.29	44.16

31	32	33	34	35	36	37	38	39	40	
13.21	13.55	13.9	14.26	14.63	15.01	15.4	15.8	16.21	16.63	
1574	**1614**	**1656**	**1699**	**1743**	**1788**	**1835**	**1882**	**1931**	**1981**	
207	214	221	228	235	243	251	260	268	277	
35	36	38	39	40	41	43	44	46	47	
248	255	262	269	276	284	292	299	308	316	
14	14	14	15	15	16	16	16	17	17	
9	9	9	9	9	9	9	9	9	9	
78	80	82	84	86	89	91	93	96	98	
983	***1006***	***1030***	***1055***	***1082***	***1106***	***1133***	***1161***	***1187***	***1217***	
0	0	0	0	0	0	0	0	0	0	
983	1006	1030	1055	1082	1106	1133	1161	1187	1217	
256	262	268	274	281	288	295	302	309	316	
727	744	762	781	801	818	838	859	878	901	
727	***744***	***762***	***781***	***801***	***818***	***838***	***859***	***878***	***901***	
41.22	38.46	35.9	33.54	31.36	29.2	27.26	25.48	23.74	22.21	8.1