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THE CHALLENGES BEHIND NEW ENERGY SOURCES:
A COMPARATIVE COSTS ANALYSIS OF NUCLEAR ENERGY,
WIND AND SOLAR POWER

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INTRODUCTION

This study proposes an investigation of costs of different energy sources: a comparison will be made between nuclear energy, and two among the so called “renewable” energies, wind and solar power.

Energy supply is currently a theme of growing importance, due to the dramatic environmental and political changes that the world is experiencing.

Fossil fuels are scarce and about to finish, they lead to a higher pollution level and create a political unstable framework.

Energy dependence, the growth of the demand, concern for green house gas emissions, and the need of cut costs down, are causing improving in the technology, and consequently in the economics of alternative sources.

The attention is on new energy sources such as renewable types and nuclear power, which has seen a renaissance in the last decade, rather than on traditional sources, such as oil, gas and carbon, whose reserves will not last forever.

The reason that motivated the choice to compare costs of different electricity generations, reflects the need of approaching to energy sources from an economic point of view and, to have an insight for a deeper understanding of these issues.

Stated that the world cannot rely on traditional supply anymore, is it sustainable to invest fiercely on other sources?

And if it is, which are the best performing?

Therefore the decision to compare costs of nuclear energy, with the two most promising renewable sources, wind energy and solar power.

The first research question is whether nuclear energy economics is comparable with solar and wind economics.

It is commonly known that nuclear plants, despite prohibitive construction costs, have a cost competitive production with respect to traditional fuels.

The most relevant difference between the two kinds, is the costs structure, because of the influence of fixed and variable costs over total: energy production cost from oil, gas and carbon, is for high percentage dependent on the fuel supply, so prices are often influenced by variations in the spot market.

On the contrary, nuclear energy cost, as well as solar and wind power, has a irrelevant dependence on the supply of uranium, that is the common fuel which allow the atomic reaction.

Its fixed cost percentage is higher than the variable one; prices are therefore predictable and more stable.

Solar and wind power production costs structure, is similar to the nuclear one: high percentage of fixed costs with zero fuel costs.

However, results will show that they are much more expensive than nuclear, due to some technological limits, which affect the production cost itself.

It will be demonstrated how dramatically the load factor influence wind and solar, and that in case the technology is not improved, they will too closely depend on climate issue.

This allow to introduce the second research question: “are wind and solar sufficient for the base load electricity supply?”

This will be discussed and proved through the whole work, and a final recommendation will be given.

The theoretical framework of the Thesis is the following: the first part will be descriptive, introducing main issue on nuclear, wind and solar power.

In the first two chapters, the economics of these energy generations is analyzed, and an description of the different operating mechanisms is provided.

Afterwards, the model which finds costs for different electricity generations will be presented, allowing cost comparison among the three mentioned sources, and among different States as well.

In particular, chapter one refers to nuclear energy, which is the energy released by the nucleus of an atom in a process that takes place in plants called reactors, of which a technological overview will be given.

Components of the cost of electricity generation plants are then discussed, as well as social aspects of this widely debated energy source.

As explained throughout the chapter, there is a scarce information on nuclear operating and actual risks: nuclear social acceptance is generally low, negatively influenced by the recent Japanese accident in Fukushima, which a brief paragraph is dedicated to.

The second chapter refers to solar and wind energy; it will be based on the same framework of the previous part, with the purpose of showing relevant aspects of these two renewable sources.

Key features of cost components will be treated.

After this first part which introduces the topic in detail, a specific chapter on electricity generation costs will be proposed.

The notion of “levelised cost of electricity ” will be introduced, and there is a precise analysis of its economic, called “Electricity Generation Cost spreadsheet model”. Afterwards the results of the model will be presented, and an economic comparison of the different sources will then be allowed.

Furthermore it will be shown, by a sensitivity analysis, which cost components influence more the generation costs of these sources.

This permits hypothesis of changes for the future improving of their performances.

Chapter three is therefore the core of the all Thesis.

In the last part, there will be a description of energy policies and trends of the most important economies.

The levelised costs of electricity for renewable energies and nuclear power in the G7 States is discussed. Costs differences and their reasons are analyzed.

Italian scenarios and perspective on energy sources will be treated separately in the conclusive chapter.

Limits and relevant aspects of renewable energies use will be discussed and the nuclear option is proposed. An alternative to the current Italian energy mix is implicitly given.

I . NUCLEAR ENERGY

1.1 Overview of nuclear power

Nuclear energy is the energy released by the nucleus of an atom as the result of nuclear fission, nuclear fusion, or radioactive decay[1].

Nuclear energy originates from the splitting of uranium atoms in a process called fission[2].

At the power plant, the fission process is used to generate heat for producing steam, which is in turn processed by a turbine to generate electricity.

It is produced by a plant called reactor.

The quantities of fuel needed are very much less than for coal or oil.

One kilogram of natural uranium will yield about 20,000 times as much energy as the same amount of coal[3].

It is also called atomic energy and meant to be a cheap electricity source, leading to economies of scale savings.

Nuclear power is a significant contributor to world electricity, and its role as a major source of energy supply has been undergoing a steady re-evaluation[4].

More than 60 countries have expressed interest in exploring nuclear power, many of which are likely to bring their first reactors on-line by 2030[5].

This type of energy allows to reduce green-house gas emissions and make states energetically independent. In recent years there has been a resurgence of interest in developing nuclear power which is now under debate after the recent Fukushima accident; many Governments decided to abandon their nuclear policies and dismiss their plants while most of the countries involved in nuclear production still underline its importance and invest on research and development for a higher quality and safety standards[6].

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[1] The free dictionary website

[2] Ecoage website. Available at http://www.ecoage.it/fissione-nucleare.htm

[3] Wprld Nuclear Association, Economics of Nuclear Power, p. 2, 2011

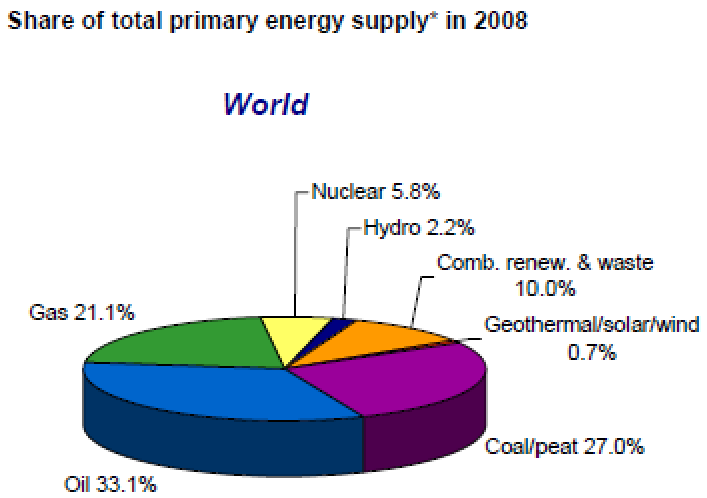
[4] John F. Ahearne, Prospects for Nuclear Energy, *Energy Economics*, 2010

[5] International Energy Agency, Annual Report, p. 1, Paris, 2010

[6] For instance, France and even Japan have deliberately said they will not phase-out their nuclear resources.

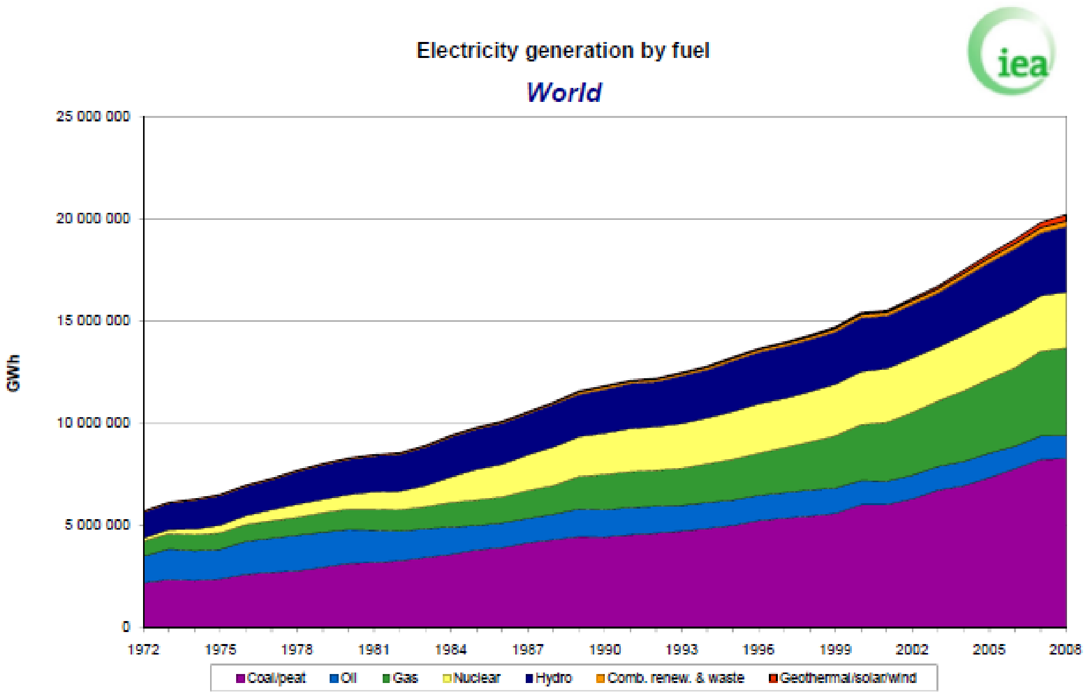
As shown by the graphs below nuclear has a relevant share of the total energy supply in the world, and even more important in the electricity production.

FIGURE 1



Source: INTERNATIONAL ENERGY AGENCY

FIGURE 2



Source: INTERNATIONAL ENERGY AGENCY

Interest in nuclear power has been revived as a result on volatile fossil fuel prices, concerns about the security of energy supplies, and global climate change[7].

Dependence on energy imports carries a large risk of power supplies: for many countries, a large percentage of the fuel needed for their economies may be at sea, or in pipelines traversing politically unstable regions.

Nuclear fuel may also have to be imported and transported but it is easy to stockpile sufficient imported uranium to operate the supply system for many years[8].

Uranium has significant advantages: low cost, easy storage and it will not degrade in storage.

The cost of electricity generation plants consists of three major components[9]:

- capital or construction costs
- operation and maintenance
- fuel cost.

Nuclear power also includes a fourth major components: back end one costs, those related to the decommissioning of the plant at the end of its operating life and disposal of the radioactive waste.

Given that the only fuel cost can create electricity cost volatility, atomic energy is said to be immune to fuel volatility relative to gas-fired station. For instance, a doubling in the price of uranium, would cause only a 5% increase in the total cost of generation, while the same increase in natural gas price would result in a 65% increase.

Thus, nuclear power allows to keep prices stable given the low dependence of the price of nuclear produced kilowatt-hours on the price of uranium[10].

Like renewable energy sources, nuclear is a low green-house-gas emitting technology .

If the world were not using nuclear, emission of CO_2 would some tones higher per year. Only a small quantity of radioactive gases are regularly emitted under

[7] A. Adamantiades, I. Kessides, Nuclear power for sustainable development: current satus and future prospects, *Energy Policy*, 37, p. 5149, 2009

[8] A. Adamantiades, I. Kessides, Nuclear power for sustainable development, cit., p. 5150

[9] World Nuclear Association, Economics of Nuclear Power, cit., p. 2, 2011

[10] A. Adamantiades, I. Kessides, Nuclear power for sustainable development, cit., p. 5150

controlled conditions imposed and supervised by authorities and pose no threat to the population.

The strongest growth in nuclear production is expected in non-OECD Asian countries. The annual electricity generation from nuclear growth rate of China and India is expeted to be around 9% per year. In contrast OECD Europe could see a stagnation, if some national governements such as Germany carry out their plans to phase out nuclear programs[11].

Some particular evidence is given, at an international level, to the nuclear safety culture, to make people conscious of what nuclear is and improve its social acceptance[12].

Nuclear safety is a collective responsibility for all the operators in the industry and this has led to the development of important international institutions[13].

The most important is the IAEA (International Atomic Energy Agency), which is an independent United Nations intergovernmental agency set up in 1957 to *"accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose"*[14].

The Agency, together with its then Director-General, was awarded the Nobel Peace Prize in 2005 for their efforts to prevent nuclear energy from being used for military purposes and to ensure that nuclear energy for peaceful purposes is used in the safest possible way. Following the accident that occurred in April 1986 at the Chernobyl nuclear power plant, the IAEA adopted a very wide-ranging program to guarantee the safety of nuclear plants, protection from radiation and human health.

The IAEA has also created the INIS (International Nuclear Information System) in 1970. INIS processes most of the world's scientific and technical literature on a wider range of subjects from nuclear engineering, safeguards and nonproliferation to applications in agriculture and health.

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[11] A. Adamantiades, I. Kessides, Nuclear power for sustainable development, cit., p. 5153
[12] John F. Ahearne, Prospects for Nuclear Energy, *Energy Economics*, 2010
[13] Enel & Elélectricité de France, La tecnologia Nucleare p. 31, Roma, 2011
[14] International Atomic Energy Agency The Statute ART II

The OECD has an own organ which assists its 28 member countries in maintaining and further developing the scientific, technological and legal bases required for the safe operation of nuclear power, that is the NEA[15] (OECD Nuclear Energy Agency). The WANO (World Association of Nuclear Operators) is an organization formed by nuclear operators worldwide uniting to exchange operating experiences in order to achieve the highest possible standards of safety.

1.2 History of the atomic energy

Nuclear energy was officially born in 1934 with experiments led by the Italian scientist Enrico Fermi[16].

Afterwards the German chemist Otto Hahn, was able to show the principle of nuclear fission.

By bombing the uranium with neutrons his team could separate the nucleus, thus make a huge quantity of energy available[17].This particular method was improved by Fermi in the Columbia University; he showed that while bombing, others neutrons were released, so that a reaction can be created. he was also able to create a little nuclear reactor which produced 0.5 watts, the needed quantity to turn a light bulb on.

Nuclear fission process is today basically the same[18].

During World War II, research on nuclear energy had lot of interest for military purposes by both the parts in conflict. They aimed at creating the atomic bomb, which could have determined the victory. American task force, called Manhattan project, reached the bomb first and in 1945 Hiroshima and Nagasaki were destroyed by the atomic bombs.

From then on, research on nuclear energy was conducted on a civil basis to build the first nuclear reactor generating electricity. In 1954 American president Eisenhower approved the ' Atom for Peace' project to facilitate the use of nuclear energy for civil purposes. The first nuclear plant was built in 1955 in Idaho, USA, called Borax III[19].

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[15] Nuclear Energy Association, The OECD Nuclear Energy Agency in brief, p. 3. Available at www.oecd-nea.org

[16] Ecoage website. Available at http://www.ecoage.it/storia-del-nucleare.htm

[17] Energia360 website. http://www.energia360.org/Nucleare/

[18] Amaldi, La fisica di Amaldi, vol 3, Zanichelli, Bologna, 2008.

[19] Ecoage website. Available at http://www.ecoage.it/storia-del-nucleare.htm

There has been many accidents since the first nuclear reactors was created. They are classified on a scale called INES (International Nuclear Event Scale) from 0 to 7[20].

The first reported accident were Kyshtym, in the Soviet Union in 1957. Classified scale 6, a radioactive waste bin exploded and about 270000 people were exposed to radiations. In the same year in the plant of Sellafield, UK, the reactor burned up and a radioactive cloud went through the entire Europe; 300 people died due to illnesses linked to that accident[21].

Afterwards, the well known accident of Three Miles Island in the US, ranked INES 5. This accident showed some technological limits because the reactor overheated and partially fused. A lot of toxic gases were released in the atmosphere and 3500 people were evacuated[22].

Fifteen years later, in 1986 the tremendous accident of Chernobyl took place.

The reactor overheated and the fusion of the nucleus determined an explosion. A huge cloud of radioactive material was dispersed in the air, 30 people died instantly and 2500 for cancer caused by the radioactive material[23].

World Nuclear Association findings on the topic are that:

- the Chernobyl accident in 1986 was the result of a flawed reactor design that was operated with inadequately trained personnel.
- the resulting steam explosion and fires released at least 5% of the radioactive reactor core into the atmosphere and downwind[24].

Presumably, many more people died due to that accident through the years, but there are not official data yet. Chernobyl has been the gravest nuclear accident of ever, ranked scale 7, and it has been caused by human negligence: Engineers were conducting an experiment and during the test the water temperature decreased so much that the reactor should have switched off. On the contrary, they tried to increase the temperature quickly and this caused the fusion of the nucleus.

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[20] 0: simple out of order, 7: very dangerous accident

[21] Ecoage website. Available at http://www.ecoage.it/storia-del-nucleare.htm

[22] Three Miles Island website. Available at www.**threemileisland**.org

[23] Ecoage website. Available at http://www.ecoage.it/storia-del-nucleare.htm

[24] World Nuclear Association, Chernobyl Accident, 2011

Above all the negligences, all the safety systems were turned off before the test had started.

In 1999 there has been a ranked 4 accident in Japan, in the plant of Tokaimura.

1.3 Fukushima

The last grave accident is the Fukushima accident, which took place on the 11th of March in Japan due to a dramatic earthquake and the following tsunami.

It caused astonishment and fear all over the world. Such a devastating accident is influencing decisions on energy policy in many States.

Governments must take into account what has recently happened in Japan, thinking about the nuclear option.

Fukushima accident has been first ranked level 5 of the INES scale, meaning that the nucleus has been damaged but there has been only a limited dispersion of radioactive material. But a month later, the Japanese Nuclear Safety Agency has raised it to level 7.

Thus, the accident is compared to the Chernobyl one, even though, apparently, the radioactive waste released in the atmosphere is much less relatively to the 1986 accident. Mr. Omoto of the University of Tokyo, an industry veteran who is a member of Japan's Atomic Energy Commission described main feature of the accident stressing that it was not the earthquake, nor the tsunami, which doomed the plant, but the combination of the two[25].

The earthquake itself did not do too much damage; it shook the reactor buildings slightly more than they were designed to be shaken, but they were built well and seem not to have suffered much harm. The three reactors running at the time shut down as they were meant to.

But the earthquake did one crucial other thing: it broke out the connections which brought electricity from the grid to the power plant. After the earthquake, the plant was on its own. The earthquake's effects had been only a bit worse than Fukushima's

[25] Piecing together Fukushima, The Economists' Babbage blog website. Available at http://www.economist.com/blogs/babbage/2011/05/japans_nuclear_disaster

designers had expected[26]; the tsunami which arrived just one hour later was much worse. Waves were about 15 meters long. It smashed the plant's sea water intake systems, broke diesel generators, and carried off diesel fuel tanks. All this meant that the plant no longer had the facilities to cool its reactors which, though shut down, were still generating plenty of heat.

Cooling systems that didn't require alternating current, which is what the grid or the diesel generators would have provided, worked for a while, but eventually failed. The reactors began to overheat and damage themselves.

One implication of this is that designers should think about external challenges to their reactors coming in pairs, and not necessarily alone, like earth tremors and tsunamis.

Over 12000 MWe of nuclear at the Fukushima, Onagawa, and Tokai facilities ceased operations after the earthquake and tsunami, and some of the reactors could be permanently damaged after emergency seawater pumping efforts[27]. Almost two months on, the situation is much more stable.

Systems have been set up for cleaning some of the contaminated water on the site. Proper cooling systems that bleed heat off to the air are being installed[28], as are permanent cooling systems for the spent-fuel pools. Work is being undertaken to reinforce the rickety structure in the buildings.

That will still leave years, even a decade, of hard and expensive work decommissioning the site. The amount of contaminated water that will have to be dealt with is remarkable.

1.4 Nuclear social acceptance

As said before, nuclear is supposed to be one of the promising energy sources for the next few decades, dealing with environmental issues and the uncertainty of fossil fuel supply. However , nuclear energy has some vulnerable points in the view of social acceptance [29]due to the history of its development and tremendous accidents such as

[26] Piecing together Fukushima, The Economists' Babbage blog website, cit.
[27] US Energy Information Administration, Country Analysis: Japan, 2011
[28] Piecing together Fukushima, The Economists' Babbage blog website, cit.
[29] A. Adamantiades, I. Kessides, Nuclear power for sustainable development, cit., p. 5152

Chernobyl and the recent Fukushima. Despite the rapid innovation and technological changes, nuclear energy social acceptance is therefore relatively low and still an obstacle for its development.

A Korean study published one year ago, tried to estimate the social value and the willingness to pay for nuclear energy[30].

A predictable result of the survey is that nuclear acceptance is positively related to the degree of safety perception.

The researcher showed that, if an adequate information is provided to the public, the social value of nuclear would increase approximately 68.5%[31].

This study becomes relevant because it demonstrates that social acceptance management is important as well as nuclear energy innovation.

For the diffusion of nuclear energy, barriers on public acceptance must be overcome, otherwise research and technological improvements, risk to be useless. Given that low social acceptance has obstructed nuclear diffusion, nuclear energy producers should pay more attention to those psychological aspects which could help the diffusion of the product.

A part of the literature is focused on explaining the importance of social acceptance management because people should be aware of what nuclear energy is and what risks really are, without over-estimating them.

According to Korean researchers, there is a big lack in the information system, thus nuclear energy is often perceived as something negative, something to be afraid of, and if possible, to be replaced by alternative sources[32].

A big obstacle to the implementation of nuclear facilities has often been the opposition from local resident who live near the area where nuclear plants were expected to be built. Many countries have solved that problem by providing huge subsidies to local governments.

For instance, Korea gave 300 million dollars to the government of Gyeongju for constructing low level waste facilities. Japan also paid 120 million dollar to the

[30] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1470

[31] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1475

[32] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1470

Rokkaso-mura area to build a waste repository, as well as the UK and Spain where some subsidies have been given to local communities[33].

Another example of an expensive policy is Sweden which reversed its nuclear phase-out in 2009. There were 2 competing localities, Oskarshamn and Osthammar, which both tried to host the plant, to gain the 240 million subsidy and benefit from infrastructure upgrades[34].

In European countries, the average of people favourable to nuclear energy is 20% ranging between 5% (Austria) and 40% (Sweden).

The most interesting finding of the survey is that people living in countries with nuclear plants are more supportive of nuclear energy[35] because they are more familiar with the issue, better informed on the risk and perhaps more aware of its benefits. Barriers in social acceptance for nuclear energy can be easily managed by providing precise information and making people aware of both advantages and risks of this energy source.

1.5 Operating mechanism

Like all conventional power plants, a nuclear power plant produces steam to drive a turbine at a fixed speed and produce electric power fed to the grid.

Steam is generated by heating water, in this case in the vessel, which is the container housing the nuclear reactor. The water is heated by fission (also called scission) of uranium nuclei. The thermal energy is then transformed into mechanical energy by one or more steam turbines which drive an alternator to convert it into electric energy[36].

The difference between nuclear and conventional technology lies in the way the steam is produced: nuclear technology uses the energy released by the nuclear. Nuclear fission is a physical phenomenon that takes place in the reactor.

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[33] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1471

[34] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1471

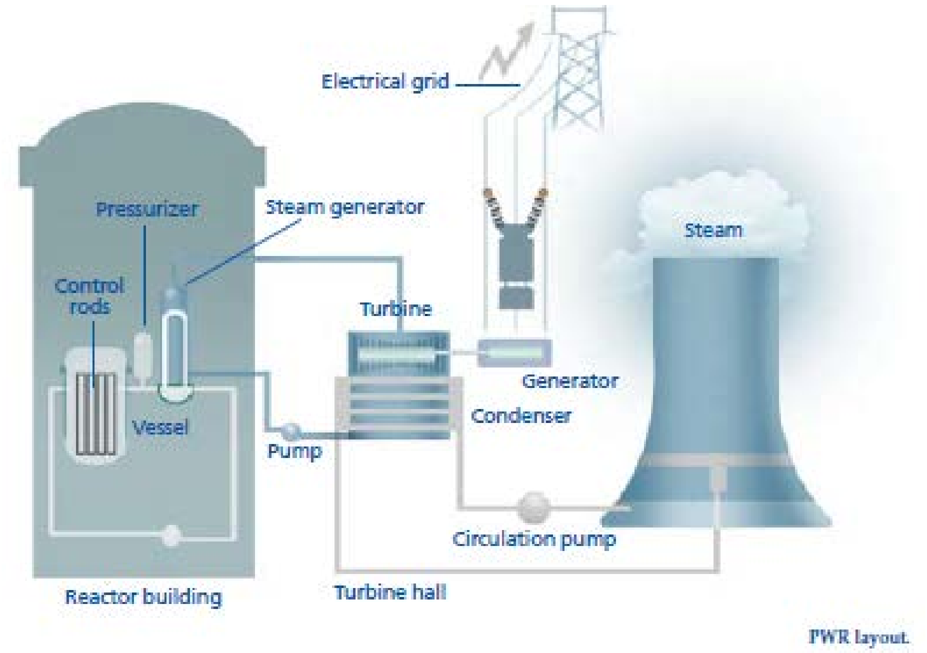
[35] Eunju Jun and others, Measuring the social value of nuclear energy using contingent valuation methodology, *Energy Policy*, p. 1474

[36] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 5

When this reaction takes place, a uranium nucleus (U-235) absorbs a neutron and divides into two lighter fragments, known as "fission products", releasing energy in the form of heat, and some neutron[37] . Fission in a reactor is a self-sustaining process.

In other words, the neutrons created by the process in turn serve to generate further fissions, in a so-called chain reaction[38].

FIGURE 3



Source: INTERNATIONAL ENERGY AGENCY[39]

The fundamental characteristic of nuclear power plants is the very small quantities of the fuel they use[40].

3737 G.P. Parodi, M. Ostili, G. Onori, L'evoluzione della Fisica, vol 3, Paravia, 2006
38 Enel & Electricité de France, La tecnologia Nucleare, cit., p. 6
39 That is a typical PWR reactor operating mechanism
40 Wprld Nuclear Association, Economics of Nuclear Power, p. 2, 2011

Most important types of reactors are:

- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR)

In a PWR the water is maintained at a pressure sufficient to prevent it from boiling and serves as both coolant and moderator. The fluid circulates in a “primary circuit”, removing the heat generated in the core and transmitting it, in one or more steam generators, to the water of a “secondary circuit” where water is transformed into steam which drives the turbo-generator[41].

This separation between the two circuits, typical of the PWR technology, has the advantage of ensuring that the steam that reaches the turbine has never been in contact with the nuclear fuel, and therefore is not radioactive as it does not contain fission products.

The primary circuit is maintained at the operating pressure of 155 bar required to keep the water in a liquid state and prevent boiling, which is undesirable in this type of reactor.

The primary water leaves the reactor at 330° and enters the steam generator. Here, it circulates in “U-shaped” steam generator tubes where it delivers its heat to the secondary water in the secondary side of the steam generator.

Generally, a current western 1300 MWe electric PWR plant needs four steam generators and therefore four primary loops[42].

In the secondary circuit the water absorbs the heat delivered by the primary circuit, and undergoes a heating and transition phase to become steam at about 290°C.

The steam is directed into the turbine where it expands and delivers its energy to the turbine making it rotate, and transforming thermal energy into mechanical energy.

In turn, the turbine drives a generator that transforms mechanical energy into electrical energy.

Lastly, the tertiary circuit discharges the residual heat coming from the condenser, delivering it either to a river or to the sea in the vicinity of the power plant or, when

[41] Enel & Electricité de France, La tecnologia EPR, p. 6, 2010
[42] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 16

such water sources are not available, to the atmosphere by means of cooling towers[43].

In a boiling water reactor (BWR), production of heat and steam takes place directly within the vessel, which in this case is therefore also a steam generator.
This kind of reactor is conceptually similar to the type described above (PWR): in BWR reactors too, the water serves as both coolant and moderator. The main difference is that there are no separate circuits (primary and secondary)[44].
In this type of reactor the steam produced in the pressure vessel is delivered directly to the turbine.
Compared to the PWR, the absence of external steam generators, which moreover are components subject to tube leakage or failure, simplifies the system. On the other hand, the structure of the vessel is more complex because it must also contain all the steam generator components.
The control system is finally more complicated in the BWR, thus the PWR is the most popular.

1.6 Generations III+ and IV systems

The history of nuclear power production is recent.
The first prototypes to generate electricity were launched in the 1950's[45]. Significant developments have taken place in order to produce the industrial models now in service.
The operating experience provided by these reactors has led to third generation models available today on the market.
A research program, which began in 2001 with the aim of developing new advanced projects for Generation IV reactors, is not expected to produce its initial results until after 2030[46].
Nuclear reactors can be classified according to the generation they belong to:

[43] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 17
[44] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 19
[45] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 21
[46] Tim Abram, Sue Ion, Generation IV nuclear power: a review of the state of the science

- the first generation includes prototypes and reactors for producing electricity, designed and built before and around the 1960's
- the second generation mainly comprises light water reactors, designed and in service from the 1970's and 1980's and still operating today all over the world
- the third generation, developed from the 1990's, for the first time involved standardized projects, with an increase of safety based on the experience of the first large plants of the previous generation.
- the advanced third generation refers to those advanced reactors (like the EPR and the AP1000) derived from optimization, in terms of economy and safety, of current light water reactors, and including increased resistance to core meltdown and external risks such as an aircraft impact. The European Pressurized Reactor (EPR) constitutes the advanced third generation of the most used type of reactor in the world, the Pressurized Water Reactor (PWR)[47].

Generation III+, is an evolutionary project, that benefits of the experience acquired over more than thirty years by the French and German designers and operators, whilst at the same time constituting a further development step, above all in the areas of safety, protection of man and the environment, efficiency and economy, as well as being scaled up to an electrical power output of 1600 MWe.

This type of reactor represents an evolution compared to the previous generation in terms of:

- enhanced safety systems
- improved fuel technology
- protection of the environment
- efficiency and economy[48].

[47] Enel & Electricité de France, La tecnologia Nucleare, cit., p. 21
[48] Enel & Electricité de France, La tecnologia EPR, p. 6, 2010

Furthermore, the EPR has been designed to also use MOX (mixed oxide fuel, fuel that contains uranium and plutonium oxides); therefore the EPR can use plutonium as a fuel and extract energy from its fission rather than have to dispose of it as waste[49]. The improved efficiency of the plant derives from several advances which together contribute to a better exploitation of resources.

This reactor is larger than previous PWR reactors; in fact it generates the highest power ever installed to date, around 1600 MWe, and reduces investment costs by maximizing economies of scale[50].

Based on the agreement reached on 30 November 2007 between Enel and EDF, Enel has a participation of 12,5% in the construction of the Flamanville EPR unit.

Moreover, Enel will participate in the second French EPR which will start in 2012 at the Penly site[51].

The fourth generation includes innovative nuclear systems, including fast reactors associated with a uranium/plutonium closed fuel cycle, which will probably reach technical maturity from 2030 and should be available for commercial applications after 2050[52].

The activities are guided by the Generation-IV International Forum (GIF)[53],established in 2000, which seeks to develop a new generation of nuclear energy systems for commercial deployment by 2020–2030[54].

These systems include both the reactors and their fuel-cycle facilities.

The aim is to provide significant improvements in economics, safety, sustainability, and proliferation resistance[55].

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[49] Enel & Electricité de France, La tecnologia EPR, p. 13, 2010

[50] Enel & Electricité de France, La tecnologia EPR, p. 13, 2010

[51] Enel & Electricité de France, La tecnologia EPR, p. 16, 2010

[52] Tim Abram, Sue Ion, Generation IV nuclear power: A review of the state of the science, *Energy Policy*, 36, p. 4323, 2008

[53] The Generation IV International Forum (GIF) is a cooperative international endeavor organized to carry out the research and development (R&D) needed to establish the feasibility and performance capabilities of the next generation nuclear energy systems. The Generation IV International Forum has thirteen Members which are signatories of its founding document, the GIF Charter. Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, the United Kingdom and the United States

[54] Tim Abram, Sue Ion, Generation IV nuclear power, cit., p. 4323

[55] Generation IV International Forum, GIF R&D Outlook for Generation IV Nuclear Energy Systems, 2009

The systems selected for development are:

- the very high-temperature gas- cooled reactor (VHTR)
- the sodium-cooled fast reactor (SFR), the gas-cooled fast reactor (GFR)
- the lead- cooled fast reactor (LFR)
- the molten salt reactor (MSR) and the super-critical water-cooled reactor (SCWR)[56].

Although some systems offer similar potential capabilities, the first aim of Generation-IV will be to study the relative feasibility of all six systems, with the purpose of focusing future activities on perhaps two or three systems only.

The VHTR is the next generation in the development of high-temperature reactors and is primarily dedicated to the cogeneration of electricity, hydrogen, and process heat for industry. The high outlet temperature also makes it attractive for the chemical, oil, and iron industries because it would supply large amounts of heat.
In the near term, the VHTR will be developed using existing materials, whereas its long-term development will require new and advanced materials[57].

The sodium-cooled fast reactor (SFR) uses liquid sodium as the reactor coolant, allowing high power density with low coolant volume fraction.
Plant size options under consideration range from small, 50 to 300 MWe modular reactors to larger plants up to 1500 MWe.
The SFR closed fuel cycle enables regeneration of fissile fuel and facilitates management of high-level waste in particular, plutonium and minor actinides[58].

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[56] Tim Abram, Sue Ion, Generation IV nuclear power, cit., p. 4324
[57] Generation IV International Forum, GIF R&D Outlook for Generation IV Nuclear Energy Systems, cit., p. 4
[58] Generation IV International Forum, A Technology Roadmap for Generation IV Energy Systems, p. 15, 2002

The SCWR is a high-temperature, high-pressure water-cooled reactor that operates above the thermodynamic critical point of water (374°C, 22.1 MPa).
The reference plant has a 1500-MWe power level and the main advantage of the SCWR is improved economics because of the higher thermodynamic efficiency (up to about 50% versus 34% for light water reactors today) and the potential for plant simplification[59].

The GFR is a high-temperature, helium-cooled fast reactor with a closed fuel cycle. It combines the advantages of fast-spectrum systems with those of high-temperature systems. The fast spectrum affords more sustainable use of uranium resources and waste minimization through fuel recycling and burning of long-lived actinides, and the high temperature affords high-thermal-cycle efficiency and industrial use of the generated heat[60].

The LFR features a fast-neutron spectrum and a closed fuel cycle for efficient conversion of fertile uranium. An important feature of the LFR is the enhanced safety that results from the choice of a relatively inert coolant provided that issues of the weight and corrosive nature of lead can be overcome.
It has the potential to meet the electricity needs of remote sites as well as for large grid-connected power stations[61].

The MSR fuel is unique in that it is dissolved in the fluoride salt coolant. MSRs have lower fissile inventories, no radiation damage constraint on fuel burn up, no fabrication of fuel forms, no spent nuclear fuel assemblies.
In addition, the development of higher temperature salts as coolants would open the MSR to new nuclear and non-nuclear applications[62].

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[59] Generation IV International Forum, GIF R&D Outlook for Generation IV Nuclear Energy Systems, cit., p.6
[60] Tim Abram, Sue Ion, Generation IV nuclear power, cit., p. 4326
[61] Generation IV International Forum, A Technology Roadmap for Generation IV Energy Systems, cit., p. 15,
[62] Tim Abram, Sue Ion, Generation IV nuclear power, cit., p. 4328

II . RENEWABLE ENERGIES: SOLAR AND WIND POWER

The necessity of a long-term sustainable deployment of renewable energy source, has got a large consensus among States and energy experts. The idea behind those needs is well-expressed by the CEO of the International Energy Agency in the forewords for the " Wind energy Technology Roadmap", dated 2010:

"Current trends in energy supply and use are patently unsustainable, economically, environmentally and socially. Without decisive action, energy-related emissions of CO_2 will more than double by 2050 . We can and must change our current path, but this will take an energy revolution and low-carbon energy technologies will have a crucial role to play. Energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power and new transport technologies will all require widespread deployment if we are to reach our greenhouse gas emission goals. Every major country and sector of the economy must be involved. The task is also urgent if we are to make sure that investment decisions taken now do not saddle us with sub-optimal technologies in the long term". Nobuo Tanaka, IEA Executive Director[63].

2.1 Solar power

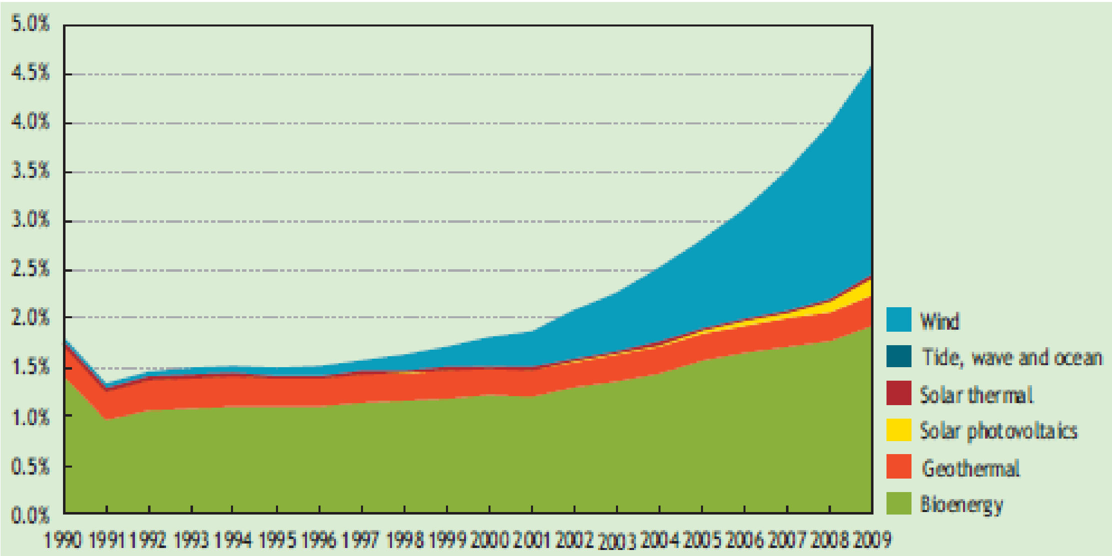
Solar energy is the most abundant energy resource on earth.
The solar energy that hits the earth's surface in one hour is about the same as the amount consumed by all human activities in a year. It provides for only the 0.1% of total global electricity generation[64].
However, it is expanding very rapidly due to effective supporting policies and recent dramatic cost reductions. Photovoltaic is now an almost commercially available technology, with a significant potential for long-term growth in nearly all world regions. Supported by a concerted policy, it is projected to provide 5% of global electricity consumption in 2030, rising to 11% in 2050[65].

[63] International Energy Agency, Wind energy, Technology Roadmap, Paris, 2010
[64] International Energy Agency, Solar energy, Technology Roadmap, p. 5, Paris, 2010
[65] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 5

Over the past decade, the photovoltaic market has experienced unexpected growth. The industry experienced significant growth in 2010 when capacity additions grew from 7.2GW installed in 2009 to 16.6 GW in 2010.

The total installed capacity in the world now amounts to around 40 GW, producing some 50 terawatt-hours of electrical power every year[66].

FIGURE 4



SOURCE: INTERNATIONAL ENERGY AGENCY

As shown by the graph, the amount of solar photovoltaic over total electricity generation is not yet relevant, compared to wind power or bio energy.

Although this technology is becoming day by day more competitive, much of the progress in recent years has been very heterogeneous, varying from country to country, due to several factors, the most important being different national regulations and incentive schemes.

This major increase was linked to the rapid growth of the German and Italian markets. With 7.4 GW installed in just one year[67], Germany, the most mature market today, the country continues to dominate the solar power market world-wide[68].

[66] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 11

[67] Data of 2010

Italy installed 2.3 GW, starting to exploit some of the potential of its huge solar resources. Other countries also saw significant growth, such as the Czech Republic which rose to 1.5 GW in 2010. Out of the European boundaries, Japan and the USA almost reached 1GW respectively, installed last year. In Europe, Spain and France are the latest for installed capacity, but are experiencing a rapid growth too.

The entire European Union installed slightly more than 13 GW of in 2010 while the rest of the world accounted for over 3 GW[69].

Solar energy can be divided into three kinds of electricity sources:

- solar photovoltaic (PV), which generates electricity through the direct conversion of sunlight
- concentrating solar power systems (CSP) use concentrated solar radiation as a high temperature energy source to produce electrical power and drive chemical reactions[70]
- solar heating and cooling (SHC) uses the thermal energy directly from the sun to heat or cool domestic water or building spaces[71].

These three ways of harnessing the sun are complementary, rather than directly competitive.

2.2 Operating

Photovoltaic systems directly convert solar energy into electricity. The basic building block of a solar power system is the photovoltaic cell, which is a semiconductor device that converts solar energy into direct current electricity. PV cells are interconnected to form a module, typically up to 50-200 watts. The PV modules combined with a set of additional application dependent system components (e.g.

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[68] Data of 2010

[69] European Photovoltaic Industry Association, Global market outlook for photovoltaic until 2015, p.4, Brussels, 2010

[70] CSP is typically applied in relatively large scale plants under very clear skies and bright sun. The availability of thermal storage and fuel backup allows CSP plants to mitigate the effects of sunlight variability.

[71] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 6

inverters, batteries, electrical components, and mounting systems), form a photovoltaic system[72].

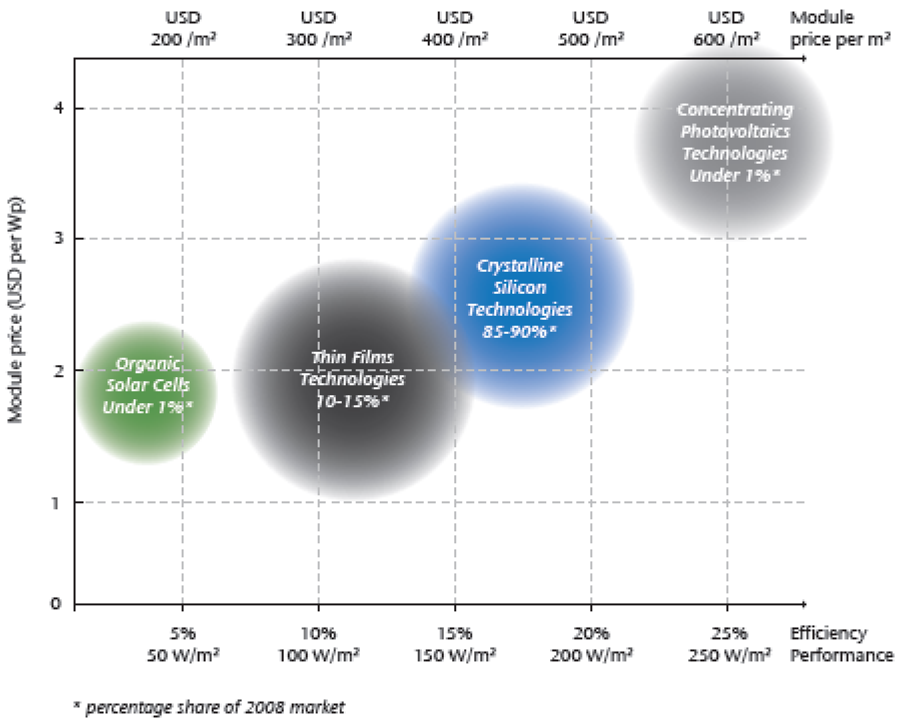
There are a range of emerging technologies, including concentrating photovoltaic and organic solar cells, as well as novel concepts with significant potential for performance increase and cost reduction.

Concentrator technologies use an optical concentrator system which focuses solar radiation onto a small high-efficiency cell.

The large variety of applications allows for a range of different technologies to be present in the market, from low-cost, lower efficiency technologies to high-efficiency technologies at higher cost.

Note that the lower cost (per watt) to manufacture some of the module technologies[73], namely thin films, is partially offset by the higher area-related system costs, namely costs for mounting and the required land, due to their lower conversion efficiency.

FIGURE 5



SOURCE: INTERNATIONAL ENERGY AGENCY

[72] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 7
[73] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 7

2.3 Photovoltaic performance and costs

Conversion efficiency, defined as the ratio between the produced electrical power and the amount of incident solar energy per second, is one of the main performance indicators of solar cells and modules. As shown by the last graph, the most efficient modules is the crystalline silicon modules which rate ranges from 14% to 20%[74].

The investment costs of those systems are relatively high, although they are decreasing rapidly as a result of technology improvements and economies of volume and scale.

High investment costs, or total system costs, represent the most important barrier to solar power deployment today[75]. Total system costs are composed of the sum of module costs plus the expenses for the balancing the system, including mounting structures, inverters, cabling and power management devices.

Total system costs are sensitive to economies of scale and can vary substantially depending on the type of application. Typical turn-key prices in 2008 in leading market countries ranged from USD 4000 /kW for utility scale[76], multi-megawatt applications, to USD 6000 /kW for small-scale applications in the residential sector.

Associated levelized electricity generation costs from PV systems[77] depend heavily on three factors:

- the amount of yearly sunlight irradiation
- the capacity factor
- the discount rate

Solar power systems do not have moving parts, so variable costs such as operating and maintenance (O&M) costs are relatively small, estimated at around 1% of capital investment per year[78].

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[74] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 7

[75] P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, *Energy Policy* 35 (2007),2855

[76] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, p.62, Paris.

[77] A separate chapter will be dedicated to the levelized costs f electricty

[78] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 7

There are four end-use sectors with distinct markets for photovoltaic:

- residential systems, typically up to 20 kW systems on individual buildings
- commercial systems, up to 1 MW systems for commercial office buildings, schools, hospitals, and retail
- utility scale systems, starting at 1 MW, mounted on buildings or directly on the ground
- off-grid applications[79].

These different applications have different system costs and compete at different price levels.

Ground-mounted large-scale installations with a generation capacity in the tens of megawatts have gained a considerable market share in recent years.

As a result, off-grid systems now constitute less than 10% of the total solar power market; however, such applications still remain important in remote areas and in developing countries that lack electricity infrastructure.

There are some limits in the large scale deployment of solar energy.

The limited flexibility of base load generators, produces increasingly large amounts of unusable PV generation[80].

In theory, this technology would have the technical potential to supply all of the electricity demand in a big area, and to virtually eliminate carbon emissions from the electric power sector.

The intermittency of solar energy, however, presents critical challenges in integrating large-scale PV into the electricity grid. This intermittency ultimately may limit the potential contribution of PV to the electricity sector.

Unlike conventional generators, intermittent sources of electricity cannot respond to the variation in normal consumer demand patterns[81]. Rapid fluctuations in output can impose burdens on generators and limit their use.

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79 International Energy Agency, Solar energy, Technology Roadmap, cit., p. 10

80 P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, cit.,2855

81 P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional

Although the ability to integrate fluctuating sources is improving[82], there is a somewhat absolute limit to the economic integration of renewable energy sources such as solar PV, based on the fundamental mismatch of supply and demand. Only so much solar power can be integrated into an electric power system before the supply of energy exceeds the demand.

This likely represents the ultimate limit on system penetration of intermittent renewable in conventional electric power systems.

The concentration of solar output in a relatively narrow daily window produces unusable energy, and hence unusable photovoltaic capacity, which will increase costs beyond a point that is determined by a system's flexibility[83]. This increase in cost will inhibit the ability to achieve very high penetration.

2.4 Concentrating solar power

The sunlight hits the earth's surface both directly and indirectly, through numerous reflections and deviations in the atmosphere. On clear days, direct irradiance represents 80% to 90% of the solar energy reaching the earth's surface.

On a cloudy or foggy day, the direct component is essentially zero. The direct component of solar irradiance is of the greatest interest to designers of high temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses, whereas the diffuse component cannot[84][85].

Unlike solar photovoltaic technologies, CSP has an inherent capacity to store heat energy for short periods of time for later conversion to electricity[86].

When combined with thermal storage capacity, plants can continue to produce electricity even when clouds block the sun or after sundown.

These factors give concentrating solar power the ability to provide reliable electricity that can be dispatched to the grid when needed.

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electric power systems, cit.,2855

[82] International Energy Agency, Solar energy, Technology Roadmap, cit., p. 30

[83] P. Denholm, R.M. Margolis Evaluating the limits of solar photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies, *Energy Policy* 35 (2007), 4424

[84] Concentrating the sun's rays thus requires reliably clear skies, which are usually found in semi-arid, hot regions

[85] International Energy Agency, Concentrating Solar Power, Technology Roadmap, p. 9, Paris, 2010

[86] International Energy Agency, Concentrating Solar Power, Technology Roadmap, cit., p. 7

Collectively, these characteristics make it a promising technology for all regions with a need for clean, flexible, reliable power[87].

The basic concept of concentrating solar power is simple: it devices concentrate energy from the sun's rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy, by turbines or other engines, and then into electricity[88].

As of early 2010, the global stock of concentrating solar power plants neared 1 GW capacity. Projects now in development or under construction in more than a dozen countries (including China, India, Morocco, Spain and the United States) are expected to total 15 GW[89].

The concept of thermal storage is simple too: throughout the day, excess heat is diverted to a storage material, for instance molten salts. When production is required after sunset, the stored heat is released into the steam cycle and the plant continues to produce electricity.

Concentrating solar power as described so far seems to be the perfect solution to the inefficiencies of solar photovoltaic, but it is usually not competitive in wholesale bulk electricity markets, except perhaps in isolated locations such as islands or remote grids, so in the short term its deployment depends largely on incentives.

Initial investment costs are likely to fall steadily as plants get bigger, technology improves and the financial community gains confidence in concentrating solar power. In the near term, its economics is not favorable for base load electricity production.

Levelized energy costs, which estimate a plant annualized lifetime cost per unit of electricity generation, range from USD 200 MW/h to USD 295 MW/h for large trough plants, the technology for which figures are most readily available[90]. The actual cost depends mostly on the available sunlight. The impact of storage on generating costs is not as simple as it may seem.

[87] International Energy Agency, Concentrating Solar Power, Technology Roadmap, cit., p. 7
[88] International Energy Agency, Concentrating Solar Power, Technology Roadmap, cit., p. 9
[89] International Energy Agency, Concentrating Solar Power, Technology Roadmap, cit., p. 9
[90] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p.62

2.5 Wind Power

Wind energy, like other power technologies based on renewable resources, is widely available throughout the world and can contribute to reduce energy import dependence, entailing no fuel price risk or constraints[91].

To give an idea of the diffusion of wind energy, in 2008, it provided for nearly 20% of electricity consumption in Denmark, more than 11% in Portugal and Spain, 9% in Ireland and nearly 7% in Germany, over 4% of all European Union (EU) electricity, and nearly 2% in the United States[92].

In 2008, more than 27 GW of capacity were installed in more than 50 countries, bringing global capacity onshore and offshore to 121 GW[93].

In contrast to the situation on land, deployment offshore is at an early stage.

By the end of 2008, approximately 1.5 GW had been installed, mainly in the Baltic, North and Irish Seas: off the coasts of Denmark, the United Kingdom, the Netherlands, Ireland, Sweden and Belgium[94].

The average grid connected turbine has a capacity of about 1.6 MW[95].

2.6 Operating and performance

This technology extracts energy from the wind by means of a horizontal rotor, upwind of the tower, with three blades that can be pitched to control the rotational speed of a shaft linked via a gearbox to a generator, all housed on the top of the tower.

Today's offshore wind turbines are essentially marine versions of land turbines with, for example, enhanced corrosion protection[96].

The availability of a wind turbine is the proportion of time that it is ready for use.

[91] International Energy Agency, Wind energy, Technology Roadmap, cit., p. 6, 2010
[92] International Energy Agency, Wind energy, Technology Roadmap, cit., p. 8, 2010
[93] International Energy Agency, Wind energy, Technology Roadmap, cit., p. 8, 2010
[94] International Energy Agency, Wind energy, Technology Roadmap, cit., p. 9, 2010
[95] Global Wind Energy Council, available at http://www.gwec.net/
[96] International Energy Agency, Wind energy, Technology Roadmap, cit., p. 9, 2010

Onshore availabilities are more than 97% while availability of offshore turbines ranges from around 80% to 95%, reflecting the youth of the technology. A turbine lifetime is ranging between 20 and 25 years[97].

An important difference between wind power and conventional electricity generation is that wind power output varies as the wind rises and falls. Thus wind power is dependent on climate issue as solar power.

This kind of energy is considered to be fully commercial today only at sites with high wind speeds on land. Capital costs of onshore wind energy projects are dominated by the cost of the wind turbine[98].

The key elements that determine the basic costs of wind energy are:

- Upfront investment costs, mainly the turbines
- The costs of wind turbine installation
- The cost of capital, i.e. the discount rate
- Operation and maintenance (O&M) costs
- Other project development and planning costs
- Turbine lifetime
- Electricity production, the resource base and energy losses[99].

Approximately 75% of the total cost of energy for a wind turbine is related to upfront costs, such as the cost of the turbine, foundation, electrical equipment, grid-connection and so on. All those costs which are considered to be fixed[100].

Obviously, fluctuating fuel costs have no impact on power generation costs. Thus a wind turbine is capital-intensive compared to conventional fossil fuel technologies such as a natural gas power plant, where as much as 40-70% of costs are related to fuel and O&M.

Operation and maintenance costs for onshore wind energy are generally estimated to be around 1.2-1.5 c€/kWh of wind power produced over the total lifetime of a

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[97] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p.43

[98] The European Wind Energy Association, The Economics of Wind Energy, p. 30,

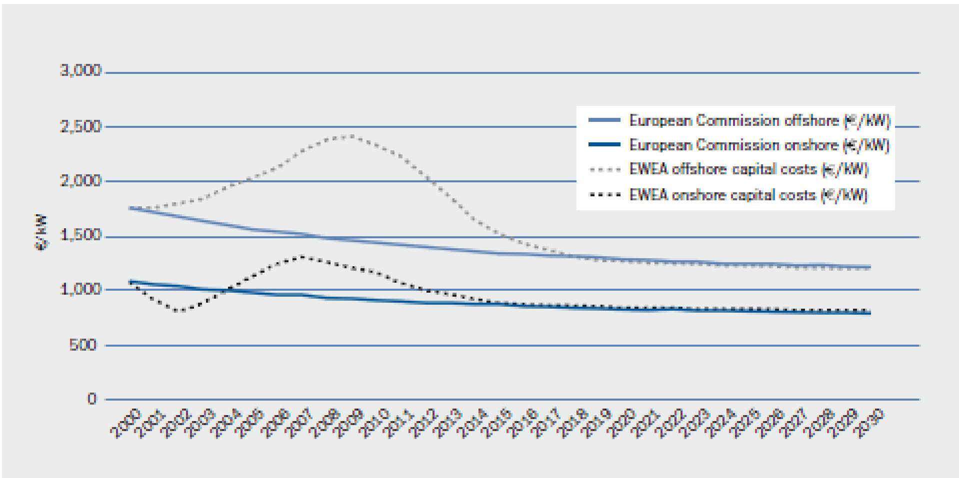
[99] The European Wind Energy Association, The Economics of Wind Energy, cit., p. 29

[100] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p.40

turbine. The remaining 40% is split equally between insurance, land rental and overheads. The costs range from approximately 7-10 c€/kWh at sites with low average wind speeds, to approximately 5-6.5 c€/kWh at windy coastal sites, with an average of approximately 7c€/kWh at a wind site with average wind speeds[101].

FIGURE 6

FIGURE 1.7: Cost of onshore and offshore wind (€/kW)
European Commission/EWEA assumptions



SOURCE: EUROPEAN WIND ENERGY ASSOCIATION

After the investment is paid off, the cost of producing electricity from wind energy is competitive with any other fuel based technology and, hence, generally lower than the electricity price.

The longer the wind turbine runs after the pay-back time the more profitable the investment[102].

As we learned previously, wind energy is a capital intensive technology. Once the investment is covered, the income from selling the electricity only has to be higher than the variable costs, such as O&M cost, for the turbine to keep running.

O&M costs are related to a limited number of cost components, and include:

[101] The European Wind Energy Association, The Economics of Wind Energy, cit., p. 56

[102] The European Wind Energy Association, The Economics of Wind Energy, cit., p. 38

- insurance,
- regular maintenance
- repair
- spare parts
- administration[103].

Small wind turbines remain much more expensive per kW installed than large ones, especially if the prime function is to produce grid quality electricity. This is partly because towers need to be higher in proportion to diameter in order to clear obstacles to wind low and escape the worst conditions of turbulence and wind shear near the surface of the earth. But it is primarily because controls, electrical connection to grid and maintenance are a much higher proportion of the capital value of the system in small turbines than in larger ones.
Onshore technology is now dominated by turbines in the 1.5 and 2 MW range[104].

Wind energy cost calculation will be illustrated in detail in the next chapter, using the levelised cost of electricity method.

[103] The European Wind Energy Association, The Economics of Wind Energy, cit., p. 45
[104] The European Wind Energy Association, The Economics of Wind Energy, cit., p. 40

III. PROJECTED COSTS OF ELECTRICITY GENERATION: AN ECONOMIC COMPARISON OF ENERGY SOURCES

After having presented main features of nuclear energy, solar and wind power, the analysis of economic aspects of these sources will be presented, as well as their competitiveness.

This chapter is about costs of electricity and how different variables influence these costs.

There will be the description of what is considered a milestone model for energy economists and researcher: the Electricity Generating Costs[105] model, starting from the basic unit of electricity cost, the so called Levelised Cost of Electricity[106]. Evidence will be furthermore be given to some relevant aspects of nuclear and renewable energies, and comment on their economic relevance.

This is surely the fundamental part of the whole Thesis, beyond which there will be some personnel considerations on energy policy decisions.

3.1 LEVELISED COST OF ELECTRICITY

The notion of levelised cost of electricity is a fundamental tool to compare the costs of different technologies over their economic life[107]. Comparing it with a different economic area ,it would correspond to the financial cost of producing a certain amount of electricity, assuming the certainty of production costs and electricity stability. It is an average cost of producing electricity including capital, finance, owner's costs on site, fuel and operation over a plant's lifetime, with provision for decommissioning and waste disposal[108]. Therefore, the discount rate used in the calculation of LCOE reflects the return on capital for an investor without

[105] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*. Paris, 2010
[106] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 33
[107] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 34
[108] World Nuclear Association, *The Economics of Nuclear Power*, p. 5, 2011

any specific market risks[109]. Given that, on the contrary, specific market and technology risks do exist, a gap between the results found by the formula below and the actual cost of an investor operating in real electricity markets must verify. Uncertainties and risks are not completely foreseeable. Some structural determinants, such as non-storability of electricity, peaks and variability of daily electricity demand or eventually seasonal variations, spot prices allow prices to fluctuate[110]. Even though there are some strong assumptions in the construction model of this unit for electricity costs comparison, it must be specify that LCOE remains the most transparent consensus measure of generating costs, and is widely used tool used in modelling and policy discussion[111].

The calculation of the LCOE is based on the equivalence of the present value of the sum of discounted revenues and the present value of the sum of discounted costs. In fact, the equation compares the present value of the sum of discounted costs divided by the total production, previously adjusted for its economic time value[112].

Therefore, if the electricity price results equal to le levelised average lifetime costs, an investor would precisely break even on the project. If the electricity price is higher, the project is therefore making a profit.

There are some important assumptions to have this equivalence:

- the interest rate "r" used for discounting both costs and revenues is stable over the period of the production, meaning that it does not vary during the project lifetime.
- the electricity price, indicate as "P electricity" is stable too, and does not change during the lifetime of the project.

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[109] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 34

[110] For these reasons, LCOE calculation and results are very closer to the real cost of investment in electricity production in regulated monopoly electricity markets with loans guarantees and regulated prices rather than to the real costs of an investment in competitive electricity markets with all the uncertainties described above at the same time.

[111] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 33

[112] Another way of looking at the equation below is to think that LCOE is equal to the price of output, that is the amount of electricity generated, that would equalise the two discounted cash flows.

- all output once produced, is immediately sold at that price
- variables are 'real' so net of inflation.

The results presented by the study below will depend on a 5-10% interest rate.
These two have been chosen to understand how the interests rate can affect the calculations on LCOE, and which energy types depend more on rates variations.
In fact, there is a range of possible outcomes deriving from the choice on the interest rate. We will comment later on both the upper front and the back end.
The equations should clarify these relationships. With annual discounting, the LCOE calculation begins with equation 1, expressing the equality between the present value of the sum of discounted revenues and the present value of the sum of discounted costs[113]. The letter "t" refers to the year in which the sale of production or the cost of disbursement take place. On the left hand side, the equation finds the discounted sum of all benefits and on the right side the discounted sum of all costs. The different variables in the equation are[114]:

- $Electricity_t$: the amount of electricity produced in year "t" ;
- $P_{electricity}$: the constant price of electricity;
- $(1+r)^{-t}$: the discount factor for year "t"
- $Investment_t$: investment costs in year "t"
- $O\&M_t$: operations and maintenance costs in year "t"
- $Fuel_t$: fuel costs in year "t"
- $Carbon_t$: carbon costs in year "t"
- $Decommissioning_t$: decommissioning costs in year "t"

$$\Sigma t\,(Electricity_t * P_{electricity} * (1+r)^{-t}) =$$

$$\Sigma t\,((Investment_t + O\&M_t + Fuel_t + Carbon_t + Decommissioning_t) * (1+r)^{-t}), \qquad (1)$$

[113] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 34
[114] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 34

which is followed by (2)

$$P_{electricity} = \Sigma_t ((Investment_t + O\&M_t + Fuel_t + Carbon_t + Decommissioning_t) * (1 + r)^{-t}) / (\Sigma_t (Electricity_t * (1+ r)^{-t})), \quad (2)$$

LCOE is finally equal to the price of electricity found in equation (2).

Formula 2 is actually used in this study to calculate levelised average lifetime cost on the basis of the cost of investment, operation and maintenance, fuel, carbon emissions and decommissioning. All these costs, used to calculate different level of LCOE have been provided by the OECD members countries and some selected members, like Russia, China and Brazil, and industry organisations[115]. This is also the formula used commonly to study new trends on energy by international organisations, useful in calculating cost competitiveness.

What is discounted is the value of output , that is simply the physical amount produced, times its price, and not the output itself.

Some experts quickly came to the conclusion that operation that seem to discount physical output must be the result of the necessary discount of monetary value of output, meaning its price[116].

The substitution of the price instead of physical output is possible thanks to the assumption that prices stay the same throughout the operating life of the plan[117]. This is a strong assumption, especially concerning new technologies, the so called renewable sources. The supply of electricity deriving from those sources is not

[115] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 34

[116] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 35

[117] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 35

constant over time[118], because they depend, by definition, on weather and specific climate issue. On the contrary, this assumption seems to work properly for nuclear energy, because the amount of electricity supplied by the atomic power plants can be monitored and regulated.

An important principle needs to be recalled before presenting the assumption behind the model: the study of the levelised cost of electricity refers to the base-load electricity at the plant level. This implies first, that the assumptions on load factors will systematically be at the upper limit of what is technically feasible[119]. For nuclear, coal and gas plants, a standard load factor of 85% has been chosen by the researchers[120].

Secondly, the notion of plant-level costs implies that system costs are not taken into account, therefore the impact of a power plant on the system as a whole is not considered in the model: this is an issue for all technologies, dealing with location and grid connection.

However, system externalities, are a major concern for variable energies[121], so renewable energies such as wind and solar. Since electricity cannot be stored, demand and supply must be balanced literally every second[122].

By the way, it must be said that, in the medium term, smart grids and progress in storage technology might all contribute to alleviating such constraints.

3.2 THEORETICAL FRAMEWORK

The calculation of the LCOE for were undertaken with the help of a simple spreadsheet model, according to a set of common basic assumption that I will present below. This model is called "Electricity Generation Cost spreadsheet model". Even if

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[118] Denholm Paul, Margolis Robert. *Evaluating the limits of solar photovoltaic in traditional electric power system*, 2007. Energy Policy,35, p. 2855

[119] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 35

[120] This is higher than the average observed load factors in practice, particularly for gas plants. The reason is that operators may choose to shut them down during base-load periods, when prices are low, due to their higher marginal costs.

[121] Denholm Paul, Margolis Robert. *Evaluating the limits of solar photovoltaic in traditional electric power system*, 2007. Energy Policy,35, p. 2857

[122] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 35

under some strong assumptions, which however I would doubt could be released by any other models, is intended to be a flexible structure which does not lose the coherence of comparing national cost figures for power generation of different technologies. The model considers so far 200 plants from 24 different sources, 16 OECD member countries, 4 non- member countries and 4 companies or industrial organisation: EDF, the Energy Supply Association of Australia, US EPRI and Euroelectric- VGB[123]. In practice, a number of parameters could modify the result of the model, and might be included in future models; an example of variables missing are government policies, such as loan guarantees or subsidies and taxes. Included such parameter in an model would have rendered any such comparative study over more than few countries, meaningless[124]. From the latest version of Projected dated 1983, lots of improvements are included today, and it would be exciting to imagine that a wider range of factors affecting LOEC will be included in next models, thus being more precise and close to the real price of electricity, which is very hard to calculate.

Basically, the Electricity Generation Cost spreadsheet model is composed by a series of excel worksheet and a questionnaire information, which has been sent to different entities asking about pre-construction and construction costs of the plants, refurbishment and decommissioning costs, operation and maintenance costs[125]. The parameters range from pre-construction, over 2015 (commissioning) until 2085(end of decommissioning for nuclear plants). Other basic data are included in the framework such as: capacity, load factor, plants lifetime and obviously the discount rate.

3.3 KEY ASSUMPTION AND CONVENTIONS OF THE MODEL

The purpose of these methodological conventions for calculating levelised average lifetime costs with the EGC spreadsheet model is to guarantee comparability of the

[123] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 37
[124] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 37
[125] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 37

data received, without losing the country-specific informational content[126]. The authors aimed at describing them in a satisfactory manner, which means finding a careful balance between too much and too little homogenisation. These conventions have two distinct functions:

- certain key parameters, such as discount rates, lifetimes or fuel and carbon prices, need harmonisation because they have a decisive impact on final results. Different fuel price assumptions inside a single region, say Europe, would bury all other information but reveal little about national conditions for electricity generation costs;
- in the light of occasionally incomplete or ambiguous country submissions, methodological conventions serve to complete and harmonise them [127](this concerns items such as contingency assumptions, residual value, decommissioning costs and schedules).

Wherever possible, national assumptions were taken in these cases.
Decisions on methodology were prepared by the IEA and NEA Secretariats and taken by the EGC Expert Group[128]. An overview of most important conventions and key assumptions is provided below in the chapter.

3.3.1 Discount rates

The levelised costs of electricity were calculated for all technologies for both 5% and 10%.
As the results will demonstrate, there is not a unique LCOE, but a pair of them, depending on the interest rate used. In comparing different countries and different technologies we have to be careful on both the lower and the higher cost level. In

[126] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 41

[127] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 41
[128] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 41

fact, convenience perspective can slightly change, and one could result more efficient than another depending on which discount rate has been used.

3.3.2 Fuel cycle

A number of countries provided cost data on different components of the fuel cycle. However, in order to work with the EGC spreadsheet model, cost data in terms of USD/MWh needed to be defined on a harmonised basis[129]. For uranium prices, an indicative value that did not directly enter calculations of USD 50 per pound of U_3O_8 was used for reference only[130].

- Front-end of nuclear fuel cycle

(Uranium mining and milling, conversion,
enrichment and fuel fabrication)

USD 7 per MWh;

- Back-end of nuclear fuel cycle

(Spent fuel transport, storage,
reprocessing and disposal)

USD 2.33 per MWh;

Wherever available, in a format compatible with the EGC spreadsheet model, national data was taken[131].

It must be note that uranium has the advantage of being a highly concentrated source of energy which is easily and cheaply transportable. The quantities needed are very much less than for coal or oil. One kilogram of natural uranium will yield about 20,000 times as much energy as the same amount of coal[132].

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[129] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 41

[130] World Nuclear Association, *The Economics of Nuclear Power*, cit, p, 1, 2011

[131] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 42

[132] World Nuclear Association, *The Economics of Nuclear Power*, cit, p, 1, 2011

3.3.3 Lifetimes

The EGC project figured out expected lifetimes for each technology across countries[133]:

- Wave and tidal plants, 20 years;
- Wind and solar plants, 25 years;
- Gas-fired power plants, 30 years;
- Coal-fired power and geothermal plants, 40 years;
- Nuclear power plants, 60 years;
- Hydropower, 80 years.

3.3.4 Decommissioning and residual value

At the end of a plant's lifetime, decommissioning costs were spread over a period of 10 years for all technologies[134]. In case of any positive residual value after operating the lifetime of a plant, there was a possibility to record it as well. For fossil fuel and CC(S) plants the residual value of equipment and materials shall normally be assumed to be equal to the cost of dismantling and site restoration, resulting in a zero net costs of decommissioning.

For wind turbines and solar panels, rather than decommissioning, in practice what takes place at the end of their operating lifetime is a replacement of equipment and the scrap value of the renewable installation is estimated to amount to 20% of the original capital investment[135]. In any case, wherever available, the submitted national values were used. Where no data on decommissioning costs was submitted, the following default values were used[136]:

[133] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 42

[134] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 43

[135] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 43

[136] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 43

- Nuclear energy 15% of construction costs[137];
- All other technologies 5% of construction costs.

The question of decommissioning had lead to discussions in the EGC Expert Group given that due to the levelised cost methodology, decommissioning costs become very small once discounted over 60 years, the assumed lifetime of a nuclear plant[138]. This can seem in contrast with the fact that once decommissioning costs do come due they still represent sizeable amounts of money.

For an investor however contemplating an investment today, decommissioning costs are too

far in the future and not a decisive criterion from a financial perspective. Inside the framework of the LCOE methodology of this study, the actual methodological procedure is straightforward and with that procedure levelised decommissioning costs accounted for after the end of the lifetime of a project become indeed negligible once discounted at any significant discount rate.

As reported by EGC group, in the median case, for nuclear plants, at 5% discount rate, a cost of decommissioning equivalent to 15% of construction costs translates into 0.16 USD/MWh once discounted, representing 0.2% of the total LCOE. At 10%, that cost becomes 0.01 USD/MWh once discounted, and represents around 0.015% of the total LCOE[139].

3.3.5 Treatment of fixed O&M costs and contingencies

Fixed O&M costs were allocated on an annual basis. Unforeseen technical or regulatory difficulties, are included in the last year of construction. The following conventions have been adopted if national data for contingencies was not available[140]:

[137] World Nuclear Association, *The Economics of Nuclear Power*, cit, 2011
[138] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 7, 2011
[139] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 43
[140] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 44

- Nuclear energy (except in France, Japan, Korea and United States[141]), CC(S) and offshore wind: 15% of investment costs;
- All other technologies: 5% of investment costs.

3.3.6 Capacity

Net rather than gross capacity was used for calculations[142].
Projected Costs of Generating Electricity compares plants which have very different sizes, e.g. the costs of fossil fuel plants with the cost of other technologies which normally have significantly larger size units, for example nuclear power plants. The EGC methodology does not however take into account the economies of larger multiple unit plants. It is estimated that new units built at an existing site may be 10-15% cheaper than green field units[143], if they can use, at least partially, existing buildings, auxiliary facilities and infrastructure. Regulatory approvals are also likely to be easier to get.
The number of units commissioned at the plant site also leads to a non linear reduction of per unit capital costs. If a two-unit plant is taken as a basis for comparison, the costs of the first unit may be near 25% higher because of the additional works required for the next units. For a 3-4-unit plant, capital costs may be 8-12%, and for the 5-6-unit plant 15-17%, lower than for the basic two-unit plant[144].

[141] The reasons for this decision are that CC(S), offshore wind, as well as nuclear energy in countries with only a small number of facilities constitute in some ways a first-of-a-kind technologies that require a higher contingency rate. In countries with a large number of nuclear plants, such as France, Japan, Korea and the United States, technical and regulatory procedures can be considered as running comparatively smoothly so that contingency payments higher than those for other technologies are not warranted.
[142] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 44
[143] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 44
[144] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 44

3.3.7 Construction cost profiles

Allocation of costs during the construction followed country indications. It was linear in cases where no precise indications were provided. In the absence of national indications for the length of construction periods, the following default assumptions were used:

- Non-hydro renewable sources 1 year;
- Gas-fired power plants 2 years;
- Coal-fired power plants 4 years;
- Nuclear power plants 7 years[145]

3.3.8 Others

Average OECD import price assumptions for hard (black) coal and gas were provided by the expert group, and are comparable with the assumptions used in the World Energy Outlook[146].
Those fuel prices are:

- Hard coal (OECD member countries): USD 90 per tonne;
- Brown coal (not traded): National assumptions for both price and heat content;
- Natural gas (OECD Europe): USD 10.3 per MMBtu[147];
- Natural gas (OECD Asia): USD 11.7 per MMBtu;

The EGC project works with a harmonised carbon price common to all OECD countries over the lifetime of all technologies.

- OECD countries USD 30 per tonne of CO_2;
- Non-OECD countries No carbon price.

[145] World Nuclear Association, *The Economics of Nuclear Power*, cit, p.8, 2011
[146] International Energy Agency, *World Energy Outlook*, p. 67, 2009
[147] Million British thermal units, a common unit for natural gas

Transmission and grid connection costs were disregarded even where indicated. As noted earlier, the study exclusively compares plant-level production costs.

A standard load factor of 85% was used for all gas-fired, coal-fired and nuclear plants under the assumption that they operate as base load supplier. While it is clearly understood that many gas-fired power plants are frequently used in mid-load or even peak-load rather than in base load[148], since the overarching concern of Projected Costs of Generating Electricity is with base load, the 85% assumption is used as a generic assumption also for gas-fired power plants[149].

Country-specific load factors were used for renewable energies, since they are largely site specific[150].

3.4 NUCLEAR COST

The total 20 light water reactors, reported in the study by 12 OECD member countries, 3 non member countries and 3 industry organisations, include 17 pressurised water reactors (PWRs), 2 boiling water reactors (BWRs), and one generic advanced light water Generation III+ reactor[151].

The net capacity of the reviewed nuclear reactors ranges from 954 MWe[152] in the Slovak Republic to 1650 MWe in the Netherlands, with the largest site to be constructed in China consisting of 4 units of 1000 MWe each[153]. Owing to differences in country-specific financial, technical and regulatory boundary conditions, overnight costs for the new nuclear power plants currently under consideration in the OECD area, vary substantially across the countries, ranging from as low as 1556 USD/kWe[154] in Korea (noting the generally low construction costs in

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[148] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 45

[149] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 1, 2011

[150] Denholm Paul, Margolis Robert. *Evaluating the limits of solar photovoltaic in traditional electric power system*, 2007. Energy Policy,35, p. 2853

[151] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 50

[152] Megawatt of electric capacity

[153] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 50

[154] Kilowatt of electric capacity

that country, as well as its recent experience in building new reactors) to as high as 5863 USD/kWe in Switzerland, with a median value of 4102 USD/KWe and mean of 4055 USD/kWe[155].

FIGURE 7

Table 3.2: Nuclear power plants		
Country	Technology	Net capacity MWe
Belgium	EPR-1600	1 600
Czech Republic	Pressurised water reactor (PWR)	1 150
Germany	Pressurised water reactor (PWR)	1 600
Hungary	Pressurised water reactor (PWR)	1 120
Japan	Advanced boiling water reactor (ABWR)	1 330
Korea	Optimised power reactor (OPR-1000)	954
	Advanced power reactor (APR-1400)	1 343
Netherlands	Pressurised water reactor (PWR)	1 650
Slovak Republic	VVER 440/V213	954
Switzerland	Pressurised water reactor (PWR)	1 600
	Pressurised water reactor (PWR)	1 530
United States	Advanced Gen III+ reactor	1 350
NON-OECD MEMBERS		
Brazil	Pressurised water reactor (PWR) Siemens/Areva	1 405
China	Chinese pressurised reactor (CPR-1000) (Fujian)	1 000
	Chinese pressurised reactor (CPR-1000) (Liaoning)	1 000
	AP-1000	1 250
Russia	VVER-1150	1 070
INDUSTRY CONTRIBUTION		
EDF	EPR	1 630
EPRI	Advanced pressurised water reactor (APWR)/ Advanced boiling water reactor (ABWR)	1 400
Eurelectric	EPR-1600	1 600

Source: PROJECTED COSTS OF GENERATING ELECTRICITY

3.4.1 Load factor

The study assumption for the average lifetime load factor for calculating the levelised costs of nuclear generation is 85%. The load factor is an important performance indicator measuring the ratio of net electrical energy produced during the lifetime of the plant to the maximum possible electricity that could be produced at continuous operation[156]. In 2008, globally, the weighted average load factor

[155] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 50

[156] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 51

reported for PWRs (a total of 265 reactors) was 82.27%, for BWRs (total of 94 reactors) it was 73.83%, with larger reactors (>600 MWe) exhibiting on average a 2% higher load factor than smaller reactors[157]. Lifetime load factors can be somewhat lower due to start-up periods. The generic assumption of 85% used by the EGC model[158], although a little higher than the load factors currently reported for the existing nuclear fleet, is consistent with the advertised maximum performance characteristics of the planned Generation III+ reactor designs.

3.4.2 Decommissioning

Concerning decommissioning costs of the nuclear power they have also been included in the levelised costs calculation. Where no country-specific cost figure was provided, a generic study assumption of 15% of the overnight cost has been applied[159].

Disbursed during the ten years following shut-down, the decommissioning cost is discounted back to the date of commissioning and incorporated in the overall levelised costs. While it is an important element of a nuclear power plant's operation, decommissioning, accounts instead for a smaller portion of the LCOE due to the effect of discounting. Decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. In the USA they account for 0.1-0.2 cent/kWh, which is no more than 5% of the cost of the electricity produced[160]. In particular, the fact that for nuclear power plants decommissioning costs are due after 60 years of operation and are discounted back to the commissioning date, makes the net present value of decommissioning in 2015 close to zero, even when applying lower discount rates or assuming much higher decommissioning costs[161].

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[157] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 51
[158] The World Nuclear Association reports a possible capacity of 90% for a nuclear power plant
[159] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 51
[160] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 5, 2011
[161] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 51

3.5 RENEWABLE ENERGY SOURCES COSTS

A total of 72 cost data submissions on renewable sources of electricity generation were used by the ECG working group, including 18 onshore and 8 offshore wind installations, 17 solar PV and 3 solar thermal installations, 14 hydro units, as well as 3 geothermal, 3 biogas, 3 biomass, 1 tidal and 2 wave-generating technologies[162].

3.5.1 Onshore wind

The data shows a very wide range, with overnight costs ranging from
1821 USD/KWe in France to 3716 USD/KWe Switzerland. The reported capacities range from an individual unit of 2 MW to a wind power plant consisting of 200 MW. Reported load factors range from 20% to 41%.

Costs are expected to decline as capacities expand. In retrospect, past cost reductions can be seen to demonstrate a steady "learning" or "experience" rate[163]. Learning or experience curves reflect the reduction in the cost of energy achieved with each doubling of capacity – known as the progress ratio[164].

Assuming a learning rate for onshore wind energy of 7%, investment costs might be expected to decrease consistently to around USD 1 400/kW in 2020[165].

[162] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 51

[163] National Renewable Energy Laboratory, *Study of Potential Cost Reductions Resulting from Super-Large-Scale Manufacturing of PV Modules,* p. 7, 2004

[164] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 56

[165] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 56

3.5.2 Offshore wind

The range of overnight costs for the 8 reported offshore wind projects is from 2540 USD/KWe to 5554 USD/KWe. Load factors range from 34% to 43%. Analysis suggests a higher learning rate for offshore investment costs, of 9%, giving an investment cost in 2020 in the range of USD 2500- 3000/kW[166].

FIGURE 8

Table 3.5: Renewable energy sources

Country	Technology	Net capacity MWe	Load factor %
Austria	Small hydro	2	59%
Belgium	Onshore wind	6	29%
	Onshore wind	2	26%
	Offshore wind	3.6	37%
Canada	Onshore wind	99	30%
	Offshore wind	400	37%
	Solar PV (park)	10	13%
	Solar PV (industrial)	1	13%
	Solar PV (commercial)	0.1	13%
	Solar PV (residential)	0.005	13%
Czech Republic	Onshore wind	15	25%
	Large hydro	10	60%
	Small hydro	5	60%
	Solar PV	1	20%
	Geothermal	5	70%
France	Onshore wind	45	27%
	Offshore wind	120	34%
	Solar PV	10	25%
	Biogas	0.5	80%
Germany	Onshore wind	3	23%
	Offshore wind	300	43%
	Solar PV (open space)	0.5	11%
	Solar PV (roof)	0.002	11%
Italy	Onshore wind	50	22%
	Solar PV	6	16%
Japan	Large hydro	19	45%
Netherlands	Onshore wind	3	25%
	Offshore wind	5	41%
	Solar PV (industrial)	0.03	10%
	Solar PV (residential)	0.0035	10%
	Solid biomass and biogas	11	85%
	Solid biomass	20	85%
Sweden	Large hydro	70	40%
	Wave	1 000	35%
Switzerland	Onshore wind	6	23%
	Small hydro	0.3	50%
United States	Onshore wind	150	41%
	Offshore wind	300	43%
	Solar PV	5	24%
	Solar thermal	100	24%
	Solid biomass	80	87%
	Biogas	30	90%
	Geothermal	50	87%

SOURCE: PROJECTED COSTS OF GENERATING ELECTRICITY

[166] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 56

3.5.3 Solar PV

Capacities range from 0.002 MWe, for roof panels, to 20 MWe for industrial usage; load factors range from 9.7% in the Netherlands to 24.9% in France[167]. Overnight costs exhibit a range from as low as 3067 USD/KWe for a utility-scale solar photovoltaic farm in Canada to 7381 USD/KWe in the Czech Republic.

This concludes the overview of the methodology and key assumptions adopted for calculating the LCOE from different electricity generations. While individual assumptions can be subject to discussion, one should not lose sight of their essential function, which is to render comparable large amounts of heterogeneous data[168]. That is the principal way to go about comparing different energy sources from an economic perspective.

People involved with energy in general, are sufficiently informed to know that the future cost of power generation is uncertain. As a whole, the above data serve to develop reasonable study cases, that can be starting points for finer researches.

A sensitivity analyses will be shown afterwards revealing the impact of varying certain key assumptions.

[167] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 56

[168] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 45

3.6 RESULTS ON LEVELISED COST OF ELECTRICITY

Main findings, by the Electricity Generating Costs expert group, are reported in FIGURE 3 and 4. The analysis will focus on the comparison of levelised cost of electricity produced from nuclear energy, wind and solar power.

After presenting different costs components, I would like to show that the electricity produced by nuclear plants is outperforming , except for specific cases, almost every type of renewable sources, which are nowadays much more expensive than the atomic one.

FIGURE 9

Table 3.7a: Nuclear power plants: Levelised costs of electricity in US dollars per MWh

Country	Technology	Net capacity	Overnight costs[1]	Investment costs[2]		Decommissioning costs		Fuel Cycle costs	O&M costs[3]	LCOE	
				5%	10%	5%	10%			5%	10%
		MWe	USD/kWe	USD/kWe		USD/MWh		USD/MWh	USD/MWh	USD/MWh	
Belgium	EPR-1600	1 600	5 383	6 185	7 117	0.23	0.02	9.33	7.20	**61.06**	**109.14**
Czech Rep.	PWR	1 150	5 858	6 392	6 971	0.22	0.02	9.33	14.74	**69.74**	**115.06**
France*	EPR	1 630	3 860	4 483	5 219	0.05	0.005	9.33	16.00	**56.42**	**92.38**
Germany	PWR	1 600	4 102	4 599	5 022	0.00	0.00	9.33	8.80	**49.97**	**82.64**
Hungary	PWR	1 120	5 198	5 632	6 113	1.77	2.18	8.77	29.79/29.84	**81.65**	**121.62**
Japan	ABWR	1 330	3 009	3 430	3 940	0.13	0.01	9.33	16.50	**49.71**	**76.46**
Korea	OPR-1000	954	1 876	2 098	2 340	0.09	0.01	7.90	10.42	**32.93**	**48.38**
	APR-1400	1 343	1 556	1 751	1 964	0.07	0.01	7.90	8.95	**29.05**	**42.09**
Netherlands	PWR	1 650	5 105	5 709	6 383	0.20	0.02	9.33	13.71	**62.76**	**105.06**
Slovak Rep.	VVER 440/ V213	954	4 261	4 874	5 580	0.16	0.02	9.33	19.35/16.89	**62.59**	**97.92**
Switzerland	PWR	1 600	5 863	6 988	8 334	0.29	0.03	9.33	19.84	**78.24**	**136.50**
	PWR	1 530	3 681	4 327	5 098	0.16	0.01	9.33	15.40	**54.85**	**90.23**
United States	Advanced Gen III+	1 350	3 382	3 814	4 296	0.13	0.01	9.33	12.87	**48.73**	**77.39**
NON-OECD MEMBERS											
Brazil	PWR	1 405	3 798	4 703	5 813	0.84	0.84	11.64	15.54	**65.29**	**105.29**
China	CPR-1000	1 000	1 763	1 946	2 145	0.08	0.01	9.33	7.10	**29.99**	**44.00**
	CPR-1000	1 000	1 748	1 931	2 128	0.08	0.01	9.33	7.04	**29.82**	**43.72**
	AP-1000	1 250	2 302	2 542	2 802	0.10	0.01	9.33	9.28	**36.31**	**54.61**
Russia	VVER-1150	1 070	2 933	3 238	3 574	0.00	0.00	4.00	16.74/16.94	**43.49**	**68.15**
INDUSTRY CONTRIBUTION											
EPRI	APWR, ABWR	1 400	2 970	3 319	3 714	0.12	0.01	9.33	15.80	**48.23**	**72.87**
Eurelectric	EPR-1600	1 600	4 724	5 575	6 592	0.19	0.02	9.33	11.80	**59.93**	**105.84**

*The cost estimate refers to the EPR in Flamanville (EDF data) and is site-specific.

1. Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).
2. Investment costs include overnight costs as well as the implied interest during construction (IDC).
3. In cases where two numbers are listed under O&M costs, numbers reflect 5% and 10% discount rates. The numbers differ due to country-specific cost allocation schedules.

Source: PROJECTED COSTS OF GENERATING ELECTRICITY

I will make references to traditional energy sources as well, such as coal and gas, to stress even more the relevance of nuclear production, that is the most efficient except where there is direct access to low cost of fossil fuel[169].

This is the rare case of middle-east countries or Russia[170], whose gas turbine can perform slightly better than the average nuclear plant.

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169 World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 1, 2011

170 World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 6, 2011

FIGURE 10

Table 3.7d: Renewable power plants: Levelised costs of electricity in US dollars per MWh

Country	Technology	Net capacity	Load factor	Overnight costs[1]	Investment costs[2]		Decommissioning costs		Fuel costs	O&M costs[3]	LCOE	
					5%	10%	5%	10%			5%	10%
		MWe	%	USD/kWe	USD/kWe		USD/MWh		USD/MWh	USD/MWh	USD/MWh	
Austria	Small Hydro	2	59%	4 254	4 605	4 767	0.00	0.34	0.00	4.25	48.62	92.58
Belgium	Onshore wind	6	29%	2 615	2 679	2 742	0.81	0.31	0.00	20.54	95.65	136.23
	Onshore wind	2	26%	2 461	2 522	2 581	0.84	0.33	0.00	26.03	104.43	146.78
	Offshore wind	3.6	37%	6 083	6 233	6 380	1.32	0.51	0.00	54.09	188.21	260.80
Canada	Onshore wind	99	30%	2 745	2 813	2 879	0.77	0.30	0.00	24.53/23.85	99.42	139.23
	Offshore wind	400	37%	4 496	4 715	4 937	1.02	0.39	0.00	35.50/34.55	137.26	194.93
	Solar PV (Park)	10	13%	3 374	3 457	3 538	2.18	0.84	0.00	14.96/14.49	227.37	341.72
	Solar PV (Industrial)	1	13%	4 358	4 465	4 571	2.81	1.09	0.00	13.69/13.29	288.02	435.96
	Solar PV (Commercial)	0.1	13%	6 335	6 492	6 645	4.09	1.58	0.00	11.16/10.83	409.96	625.29
	Solar PV (Residential)	0.005	13%	7 310	7 490	7 667	4.72	1.82	0.00	10.14/9.84	470.30	718.83
Czech Rep.	Onshore wind	15	25%	3 280	3 502	3 731	1.15	0.45	0.00	21.92	145.65	219.18
	Large Hydro	10	60%	19 330	21 302	23 448	0.13	0.01	0.00	6.39	231.63	459.32
	Small Hydro	5	60%	11 596	12 918	14 374	0.08	0.00	0.00	6.97	156.05	299.11
	Solar PV	1	20%	7 381	7 958	8 558	3.25	1.25	0.00	29.95	392.88	611.26
	Geothermal	5	70%	12 887	14 176	15 590	1.27	0.55	0.00	19.02	164.78	269.93
France	Onshore wind	45	27%	1 912	1 971	2 030	0.00	0.00	0.00	20.59	90.30	121.57
	Offshore wind	120	34%	3 824	3 940	4 055	0.00	0.00	0.00	32.35	143.69	194.74
	Solar PV	10	25%	5 588	5 755	5 920	1.53	0.59	0.00	80.97	286.62	388.14
	Biogas	0.5	80%	2 500	2 686	2 880	0.40	0.18	2.65	41.18	79.67	95.47
Germany	Onshore wind	3	23%	1 934	1 977	2 019	0.74	0.29	0.00	36.62	105.81	142.96
	Offshore wind	300	43%	4 893	4 982	5 070	0.91	0.35	0.00	46.26	137.94	186.76
	Solar PV (Open Space)	0.5	11%	3 267	3 340	3 411	2.71	1.05	0.00	52.85	304.59	439.77
	Solar PV (Roof)	0.002	11%	3 779	3 864	3 947	3.14	1.21	0.00	61.05	352.31	508.71
Italy	Onshore wind	50	22%	2 687	2 766	3 349	1.02	0.39	0.00	42.78	145.50	229.97
	Solar PV	6	16%	6 592	6 917	7 247	3.67	1.42	0.00	53.94	410.36	615.98
Japan	Large Hydro	19	45%	8 394	9 237	10 141	0.08	0.00	0.00	36.11	152.88	281.51
Netherlands	Onshore wind	3	25%	2 076	2 128	2 178	0.73	0.28	0.00	17.83	85.52	122.04
	Offshore wind	5	41%	5 727	5 996	6 268	1.13	0.44	0.00	10.63	128.72	196.53
	Solar PV (Industrial)	0.03	10%	5 153	5 280	5 404	4.67	1.80	0.00	35.16	469.93	704.78
	Solar PV (Residential)	0.0035	10%	6 752	6 919	7 082	6.12	2.36	0.00	57.13	626.87	934.63
	Solid BioM and BioG	11	85%	7 431	7 614	7 793	1.11	0.51	74.82	4.49	160.50	197.04
	Solid Biomass	20	85%	5 153	5 280	5 404	0.77	0.35	69.06	4.52	129.88	155.21
Sweden	Large Hydro	70	40%	3 414	3 848	4 334	0.04	0.00	0.00	15.17	74.09	139.69
	Wave	1000	35%	3 186	3 592	4 045	1.16	0.53	0.00	75.86	168.75	224.15
Switzerland	Onshore wind	6	23%	3 716	3 808	3 898	1.48	0.57	0.00	30.55	162.90	234.32
	Small Hydro	0.3	50%	4 001	4 498	5 052	0.67	0.03	0.00	59.73	111.53	169.79
United States	Onshore wind	150	41%	1 973	2 041	2 109	0.42	0.16	0.00	8.63	48.39	70.47
	Offshore wind	300	43%	3 953	4 169	4 394	0.75	0.29	0.00	23.63	101.02	146.44
	Solar PV	5	24%	6 182	6 365	6 545	0.11	0.04	0.00	5.71	215.45	332.78
	Solar Thermal	100	24%	5 141	5 518	5 913	1.85	0.71	0.00	27.59	211.18	323.71
	Solid Biomass	80	87%	3 830	4 185	4 564	0.14	0.03	6.73	15.66	53.77	80.82
	Biogas	30	90%	2 604	2 795	2 995	0.18	0.06	0.00	24.84	47.53	63.32
	Geothermal	50	87%	1 752	1 892	2 041	0.15	0.06	0.00	18.21	32.48	46.76

Source: PROJECTED COSTS OF GENERATING ELECTRICITY

Assessing the relative costs of new generating plants utilising different technologies is a complex matter and the results depend crucially on location. As previously said, the proximity to fossil fuel deposits, represents an extraordinary economic advantage, for both producers and consumers. Coal is, and will probably remain, economically attractive in countries such as China, the USA and Australia with abundant and accessible domestic coal resources. Gas is also competitive for base-load power in many places, particularly using combined-cycle plants, though rising gas prices have removed much of the advantage.

Nuclear energy is, in many places, competitive with fossil fuels for electricity generation, despite relatively high capital costs and the need to internalise all waste disposal and decommissioning costs[171].

From the beginning, the basic attraction of nuclear energy has been its low fuel costs compared with coal, oil and gas-fired plants. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication[172].

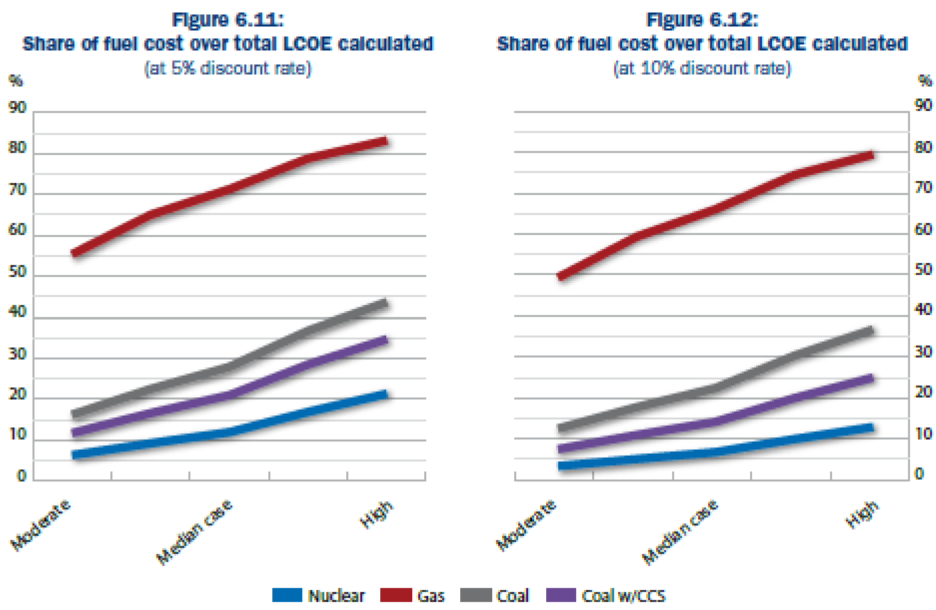
In the management of nuclear power allowances must also be made for the radioactive used fuel, that is somehow an issue that people are concerned with, and the ultimate disposal of this used fuel or the wastes separated from it.

The costs of disposing of radioactive material is considered part of the fuel cost, but even with these included, the total fuel costs of a nuclear power plant in the OECD countries, are typically smaller than for gas and coal: about a third of those for a coal-fired plants and between a quarter of those for a gas combined-cycle plants173.

Uranium is therefore intrinsically a very portable and tradable commodity. 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.

[171] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 1, 2011
[172] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 1, 2011
[173] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 1, 2011

FIGURE 11



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

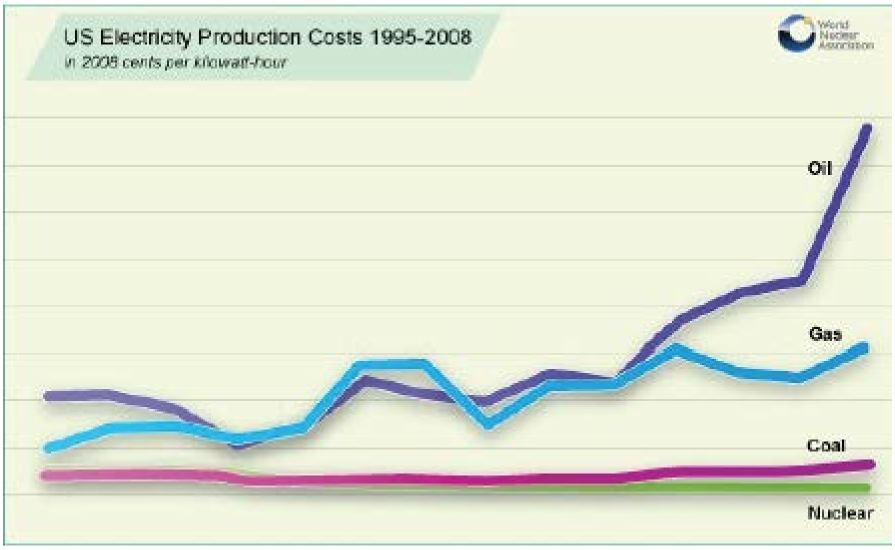
As remembered by World Nuclear Association, it is important to distinguish between the economics of nuclear plants already in operation and those at the planning stage[174]. Once capital investment are effectively amortized, existing plants operate at very low costs, and are effectively cash machines.

At this step of the life of a nuclear plant, a great percentage of the revenues accounts as a profit. This means that an investment in a nuclear power plant has a very high return on sale ratio (ROS), from its mature stage to the end (60 years lifetime on average). This is possible thank to the cost structure of a nuclear power plant: as said, it is largely composed by fixed costs (75%), thus once the revenues stream has completely covered these costs, a large amount of sales will become profits.

Their operations and maintenance (O&M) and fuel costs, including used fuel management are, along with hydropower plants, at the low end of the spectrum and make them very suitable as base-load power suppliers[175].

[174] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 2, 2011
[175] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 2, 2011

FIGURE 12



Source: THE ECONOMIS OF NULEAR POWER

The costs associated to a nuclear power plant can be broadly divided into three components: capital, finance and operating costs.

Capital and financing costs make up the project cost[176].

Capital costs comprise several things:

- the bare plant cost (engineering procurement)
- construction cost
- overnight capital costs[177]
- the owner's costs (land, cooling infrastructure, administration and associated buildings, site works, switchyards, project management, licences, etc),
- cost escalation and inflation

Owner's costs may include transmission infrastructure.

Construction costs, sometimes called "all-in cost", adds to overnight cost any escalation and interest during construction and up to the start of construction[178].

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[176] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 4, 2011

[177] The term “overnight capital cost" is often used, meaning the cost of electricity production plus owners’ costs and excluding financing

[178] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 4, 2011

In general the construction costs of nuclear power plants are significantly higher than for coal- or gas fired plants because of the need to use special materials, and to incorporate sophisticated safety features and back-up control equipment.

These contribute much of the nuclear generation cost, but once the plant is built the cost variables are minor[179].

Long construction periods will push up financing costs, and in the past they have done so widely[180].As previously said, decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. In the USA they account for 0.1-0.2 cent/kWh, which is no more than 5% of the cost of the electricity produced[181].

Operating costs include operating and maintenance (O&M) plus fuel. Fuel cost figures include used fuel management and final waste disposal. These costs, while usually external for other technologies, are internal for nuclear power[182].

This back-end of the fuel cycle, including used fuel storage or disposal in a waste repository, contributes up to 10% of the overall costs per kWh, rather less if there is direct disposal of used fuel rather than reprocessing[183].

Sellers reported in 2008 the following overnight costs:

- GE-Hitachi ESBWR just under $3000/kW
- GE-Hitachi ABWR just over $3000/kW
- Westinghouse AP1000 about $3000/kW

Nuclear overnight capital costs in OECD ranged from US$ 1556/kW for APR-1400 in South Korea through $3009 for ABWR in Japan, $3382/kW for Gen III+ in USA, $3860 for EPR at Flamanville in France to $5863/kW for EPR in Switzerland.

[179] World Nuclear Association, *The Economics of Nuclear Power*, cit p. 5, 2011

[180] In Asia construction times have tended to be shorter, for instance the new-generation 1300 MWe Japanese reactors which began operating in 1996 and 1997 were built in a little over four years, and 48 to 54 months is typical projection for plants today

[181] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 5, 2011

[182] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 5, 2011

[183] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 5, 2011

Belgium, Netherlands, Czech Rep and Hungary were all over $5000/kW. In China overnight costs were $1748/kW for CPR-1000 and $2302/kW for AP1000, and in Russia $2933/kW for VVER-1150. EPRI (USA) gave $2970/kW for APWR or ABWR, Eurelectric gave $4724/kW for EPR[184].

The following tables, proposed by World Nuclear Association, sum up the costs of different generation technologies, using separately 5% and 10% discount rates. Just to give a provocative tool of study, the single renewable energy sources chosen to be compared with nuclear and traditional sources, is on-shore wind. All the others types, as we will see later on, are not even comparable, from an economics perspective, with nuclear power.

FIGURE 13

country	nuclear	coal	coal with CCS	Gas CCGT	Onshore wind
Belgium	6.1	8.2	-	9.0	9.6
Czech R	7.0	8.5-9.4	8.8-9.3	9.2	14.6
France	5.6	-	-	-	9.0
Germany	5.0	7.0-7.9	6.8-8.5	8.5	10.6
Hungary	8.2	-	-	-	-
Japan	5.0	8.8	-	10.5	-
Korea	2.9-3.3	6.6-6.8	-	9.1	-
Netherlands	6.3	8.2	-	7.8	8.6
Slovakia	6.3	12.0	-	-	-
Switzerland	5.5-7.8	-	-	9.4	16.3
USA	4.9	7.2-7.5	6.8	7.7	4.8
China*	3.0-3.6	5.5	-	4.9	5.1-8.9
Russia*	4.3	7.5	8.7	7.1	6.3
EPRI (USA)	4.8	7.2	-	7.9	6.2
Eurelectric	6.0	6.3-7.4	7.5	8.6	11.3

Source: PROJECTED COSTS OF GENERATING ELECTRICITY

[184] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 6, 2011

FIGURE 14

country	nuclear	coal	coal with CCS	Gas CCGT	Onshore wind
Belgium	10.9	10.0	-	9.3-9.9	13.6
Czech R	11.5	11.4-13.3	13.6-14.1	10.4	21.9
France	9.2	-	-	-	12.2
Germany	8.3	8.7-9.4	9.5-11.0	9.3	14.3
Hungary	12.2	-	-	-	-
Japan	7.6	10.7	-	12.0	-
Korea	4.2-4.8	7.1-7.4	-	9.5	-
Netherlands	10.5	10.0	-	8.2	12.2
Slovakia	9.8	14.2	-	-	-
Switzerland	9.0-13.6	-	-	10.5	23.4
USA	7.7	8.8-9.3	9.4	8.3	7.0
China*	4.4-5.5	5.8	-	5.2	7.2-12.6
Russia*	6.8	9.0	11.8	7.8	9.0
EPRI (USA)	7.3	8.8	-	8.3	9.1
Eurelectric	10.6	8.0-9.0	10.2	9.4	15.5

Source: PROJECTED COSTS OF GENERATING ELECTRICITY

At 5% discount rate comparative costs are as shown above. Nuclear is comfortably cheaper than coal and gas in all countries. At 10% discount rate, nuclear is still cheaper than coal in all but the Eurelectric estimate and three EU countries[185].

Also, investment cost becomes a much greater proportion of power cost than with 5% discount. At a 10% discount rate, coal is sometimes cheaper than nuclear, like in Belgium and in the Netherlands. Only in the United States, on-shore wind seems to be cheaper than nuclear.

The calculation of LCOE shows that renewable energies are not yet competitive with respect to traditional sources and the atomic energy.

Large hydroelectric, biogas, and on-shore wind are sporadically as efficient as nuclear power. Let's analyse them separately.

Large hydroelectric is rare, even if consolidated technology, and its performance is sufficiently attractive in some Chinese sites, ranging from a minimum LCOE level of $11.49/MWh at 5% discount rate, and $23.28/MWh at a 10%.

[185] World Nuclear Association, *The Economics of Nuclear Power*, cit, p. 7, 2011

Those plants are supposed to be very performing thanks to a favourable climate conditions. By the way, this is an isolated case in a specific locations which allows such amazing costs of production.

With respect to the overall country, nuclear outstands even large hydro because China has one of the cheapest nuclear electricity production in the world. The LCOE ranges from USD 29.82/MWh (with a 5% discount rate) to a high level of USD 54.61MW/h for an AP-1000 reactor.

With regard to biogas, it allows interesting savings in the US, with a maximum production cost of $63.32/MWh. Advanced Generation III nuclear reactors in the USA perform slightly worse, with a maximum cost of $77.39/MWh.

On-shore wind is for sure the cheapest energy source among all the renewable types. Its technology needs some improvements but is already well-performing.

It would be attractive to make the off-shore wind turbines cheaper, because they have a much higher capacity.

Unfortunately, they are, nowadays, one of the most expensive technology in the industry. Thus on-shore wind, although more expensive than nuclear and not able to deal with peaks and big amounts of energy demands, is on average the cheapest renewable source, as demonstrated by World Nuclear Association.

3.7 SENSITIVITY ANALYSIS AND FACTORS AFFECTING THE LCOE

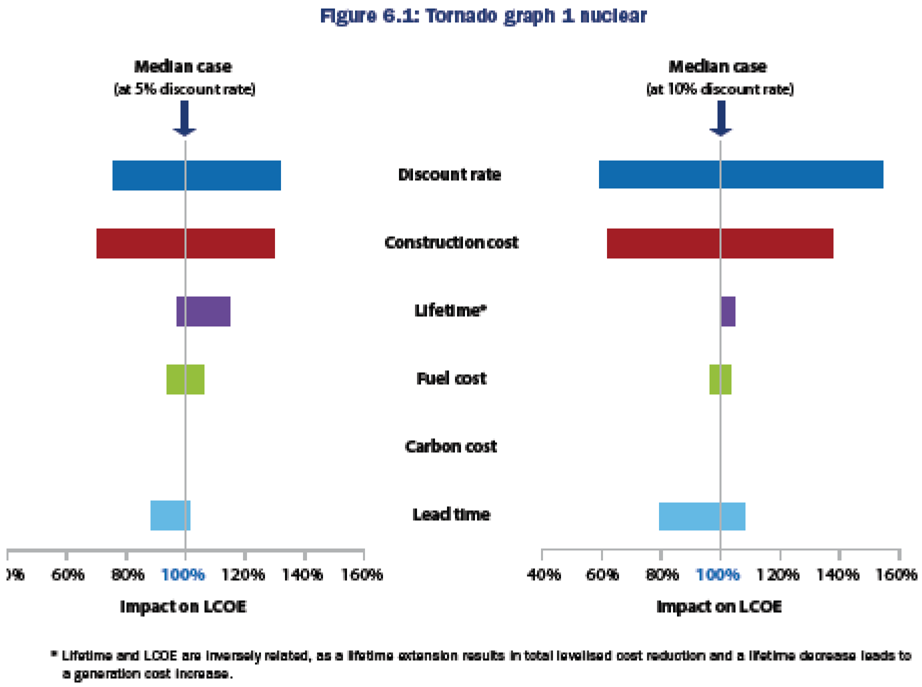
A particular analysis can be performed to test the impact of changes in underlying parameters on a LCOE, calculated using median values from the sample of OECD countries' reported data.

This analysis, developed by the Electricity Cost Generating expert group[186], is useful for understanding how cost components, such as capital, O&M, fuel and CO2 costs, influence the LCOE and which are strength and weaknesses of each technology.

Also non-economic factors, can influence the cost such as capacity, thermal efficiencies and load factors[187][188].

[186] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 106

FIGURE 15



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

The above graph show how some variables can influence the LCOE at a 5% and 10% discount rate.

The economics of nuclear energy are largely dependent on total investment costs, which are determined by both construction cost and the discount rate.

At a 5% discount rate, the key driver of the LCOE of nuclear power is construction costs, while at 10%, discount rates have a larger impact on the LCOE than any other parameter[189].

This result confirms that investment costs are the predominant in the nuclear business. A reduction in lead time also has a significant impact on total costs, in particular at a 10% discount rate due to increased interest during construction.

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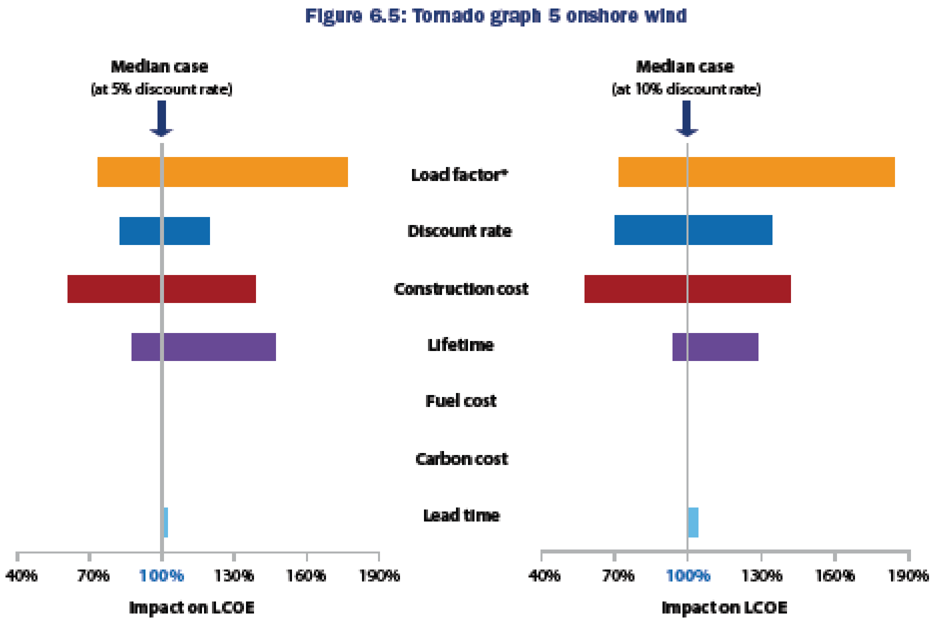
[187] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 106

[188] In the research median values were been used instead of the mean, given the wide dispersion of data among countries observed for all technologies.

[189] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 107

Construction delays, on the other hand, have a lower impact on costs[190], if the total budget remains constant, which is generally an unrealistic assumption.
In practice, cost delays often entail cost overruns[191]. Early retirement of a nuclear plant has a greater effect on total LCOE than its lifetime extension beyond 60 years, mainly due to the discounting effect.
Finally, as confirmed by the sensitivity analysis, that variations on nuclear fuel prices and services have the least impact on total LCOE.

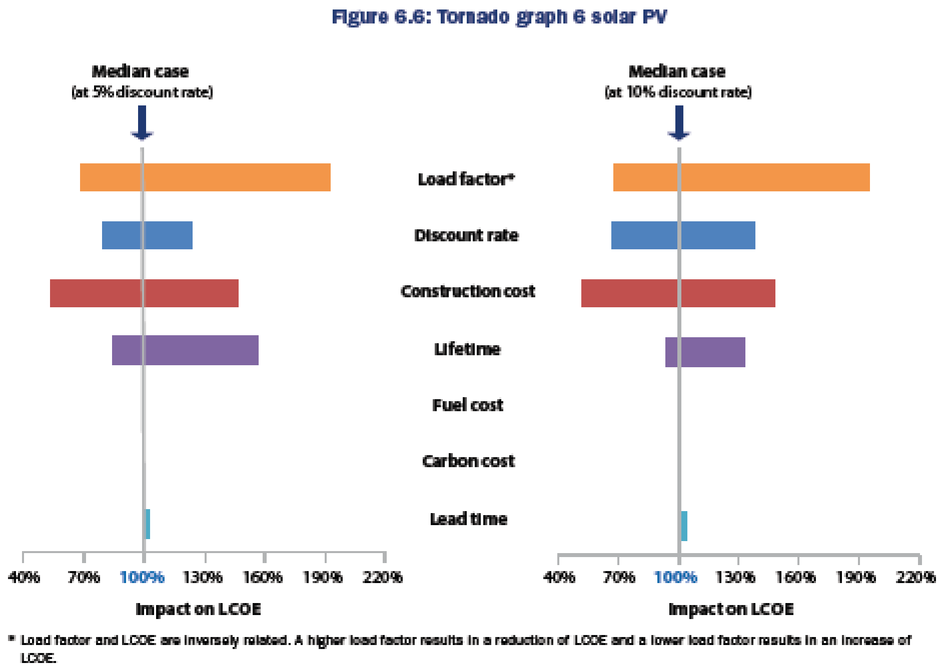
FIGURE 16



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

[190] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 107
[191] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 107

FIGURE 17



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

The levelised costs of electricity produced with onshore wind and solar photovoltaic technologies exhibit a very high sensitivity to load factor variations, and to a lesser extent to construction costs, at any discount rate[192].

The impact of variations in capacity factors is also markedly skewed to the right, meaning that plants are particularly sensitive to decreases in the load factor.

Construction cost is the second most important parameter affecting the competitiveness of renewable plants[193].

For certain renewable technologies, particularly for solar photovoltaic, as a result of learning rates, cost reducing manufacturing and technology improvements, substantial cost reductions are expected in the coming years.

At a 5% discount rate, for wind and solar technologies the operating lifetime of the plant is the next most important cost driver, after capacity factor and construction

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[192] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

[193] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

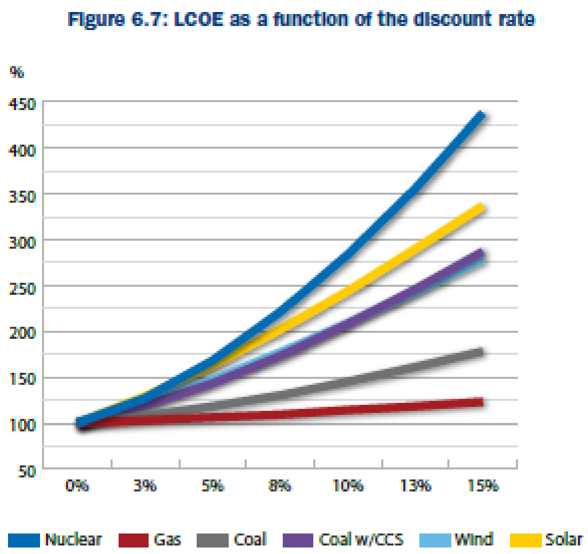
cost, with early retirement of plants having a far greater impact than life extension on total LCOE. At a 10% discount rate, the impact of further variations in the cost of capital, weighs more heavily than variations in the

operating lifetime of the plant[194].

Given the short construction times and relatively modest up-front investment compared to other generation plants, all the interests paid represents a relatively minor cost component and, despite the high capital-cost ratio, lead times become the least important cost driver for these technologies at both discount rates[195].

Finally, despite capital costs account for a large share of total LCOE in renewable plants, given their short lead times, these technologies are, among the capital-intensive technologies, the least sensitive to variations in discount rates. Load factors, which are fixed for base-load technologies (with the load factor kept constant at 85%), are of dramatic significance for renewable generation sources[196].

FIGURE 18



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

[194] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

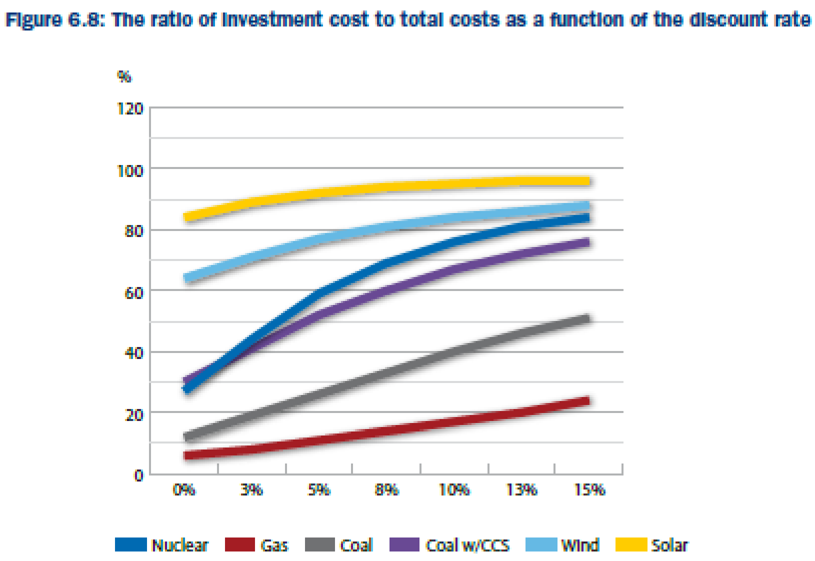
[195] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

[196] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

Logically, with an increased cost of capital the total generation cost for all technologies increases. The first observation is the relative stability of the cost of gas-fired power and hence its relative insensitivity to discount rate changes. At the other end of the spectrum, nuclear power, despite having a lower investment cost ratio than renewable technologies, is the most sensitive technology to discount rate changes, due to the fact that it has longer construction times than any other technology[197].

The graph below shows that the ratio of investment costs to total costs for nuclear power rises quicker than the one for solar or wind, even though renewable technologies initially have a much higher investment costs to total cost ratio.

FIGURE 19

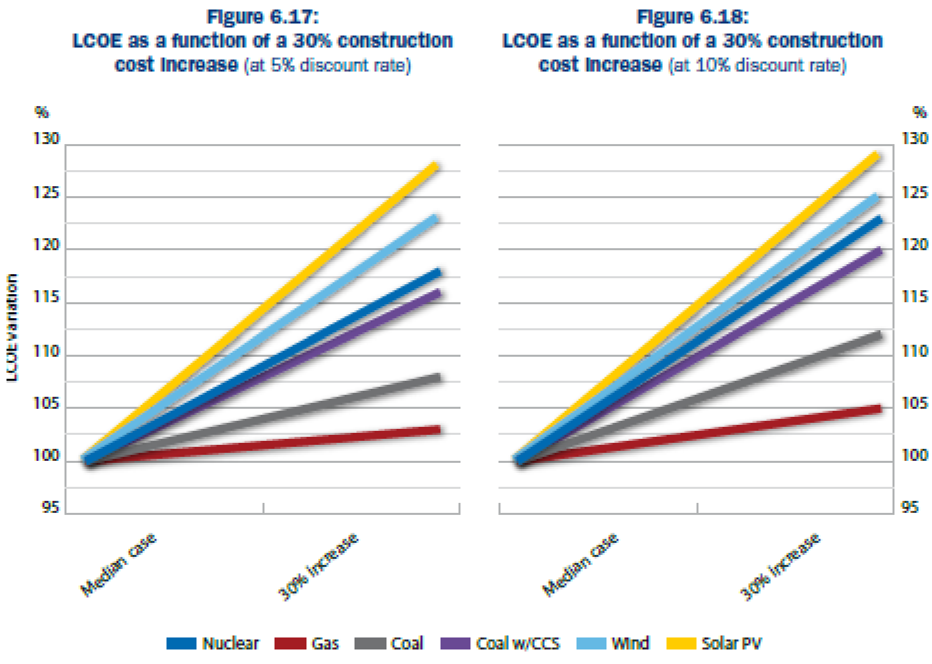


Source: PROJECTED COSTS OF GENERATING ELECTRICITY

Investment costs are certainly a key component of LCOE, for the electricity industry as a whole. Let's see what is the impact of a 30% increase in construction costs on the LCOE of different electricity generation technologies.

197 International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 113

FIGURE 20



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

The difference in the construction cost sensitivities of different plant types, can be explained by their different cost structures, share of capital investment, O&M, and fuel . Solar , for which 85-95% (depending on the discount rate used) of the LCOE corresponds to investment cost, is the technology most sensitive to changes in construction costs[198].

Levelised costs of onshore wind where investment costs account for 77-85% of total LCOE, nuclear (60-75% of total LCOE) and coal with CC(S) (51-66%)[199] are also very sensitive to the construction cost variation, particularly at a 10% discount rate. The share of the total investment cost is particularly high in a 10% discount rate environment, representing 95% of solar, 84% of wind, 76% of nuclear[200]. The cost of generating electricity from solar, nuclear and wind technologies is therefore, as one

[198] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 119

[199] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 59

[200] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 119

would expect, more sensitive to the overnight construction cost than the costs of other base-load alternatives.

The load factor of a power plant indicates the ratio of the electrical energy produced by a plant and the theoretical maximum that could be produced at non-interrupted power generation[201].

It is of considerable importance for the economics of power generation, since it defines the amount of electricity produced per unit of generating capacity.

The sensitivity analysis for the load factor variation. The figure below illustrates the evolution in the levelised costs of generating technologies as a function of load factor variation at 5% and 10% discount rates. On the vertical axis, 100% corresponds to the levelised costs of nuclear, coal and gas-fired plants at 85% load factor (generic study assumption), and to levelised costs of solar PV and wind at 25% load factor[202].

Because nuclear and coal with CC(S) have much higher fixed costs than alternative fossil fuel base load generating technologies, their total LCOE is most affected by the load factor variation, in particular at a 10% discount rate, where fixed costs weigh more heavily. Variable generation sources, wind and solar photovoltaic, where fixed costs constitute an even higher share of total

costs, are logically more sensitive to the variation of load factor.

In other words, running or not running a nuclear plant, a wind or a solar plant, makes a relevant difference to the profitability of a project, (due to the high fixed costs of these technology) since all three must resolutely cover their high fixed costs, while their variable costs are very low[203].

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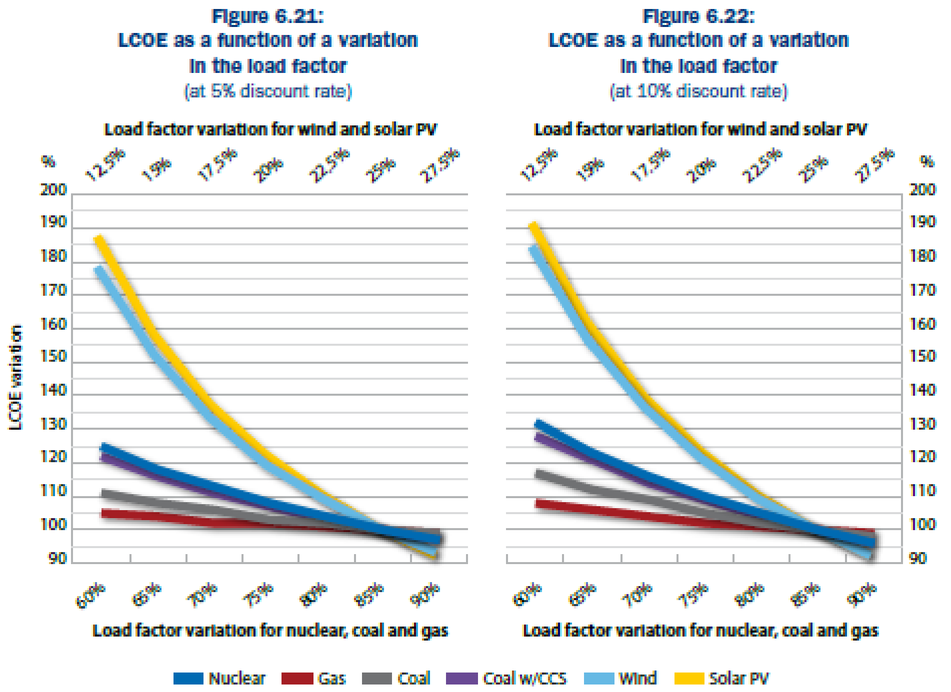
[201] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 121

[202] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 121

[203] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 121

FIGURE 21



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

3.8 FINAL COMMENTS

This has been a detailed overview on electricity costs. It is underlined how they are calculated, and which are the assumptions to figure out a proper levelised cost of electricity for different sources.

Afterwards, a description of relevant features of these energies, from an economic point of view, is presented.

After showing their convenience, I have demonstrated which factors can influence their competitiveness, and that nuclear power, although expensive at the beginning, is already a self-sustaining source of energy, while many renewable energies, such as solar and off-shore wind are not yet competitive in free-markets. If the social, health and environmental costs of fossil fuels were also taken into account[204], the

[204] Denholm Paul, Margolis Robert. *Evaluating the limits of solar photovoltaic in traditional electric power system*, 2007. Energy Policy,35, p. 2855

economics of nuclear power would consequently outstand its "rivals". In fact, as I have explained in chapter one, nuclear is a non-pollutant energy like any renewable sources; although some fossil fuel sources are still convenient, after considering their negative environmental impact, we can say that nuclear must be an option.

Furthermore, nuclear energy is a large scale base load technology, with an average capacity per reactor of 800/1000 MWe, while renewable energies are not, yet.

Wind and solar power cannot serve for base load demand because their operating mechanisms severely depend on climate issue.

Only gas, oil, coal and nuclear can deal with peaks of electricity demand and guarantee a sufficient supply level in extreme cases.

Consequently a first question may arise: " Are renewable energies the real competitors of nuclear energy? "

My belief, is that they are not.

From an economic perspective, nuclear energy is much more similar to gas and coal energy, rather than to wind and solar power. Gas plants operate from a minimum cost of USD 57.75/ MWh in Russia, (with except for China which is far below the standard costs for both nuclear and gas) to a maximum level of USD 105/MWh (USA, Switzerland) or USD 119/ MWh (Japan).

Instead, electricity from coal is produced at a minimum cost of USD 70-85/MWh in Germany and at a higher level in some sites in Czech Republic or Belgium[205]. These costs for gas and coal are closer to LCOE for nuclear rather than for on-shore wind.

Although nuclear and renewable sources share the same cost structure, wind and solar LCOE is today too far from the cost of nuclear. This is due especially to the high load factor variation and the short operating lifetime of the plants.

On the other hand, their performance is too influenced by their low capacity factor[206], which does not account in the calculation of LCOE but remains an issue dealing with peak demands.

For certain renewable technologies, particularly for solar photovoltaic, as a result of learning rates, cost-reducing manufacturing and technology improvements,

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[205] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 60

[206] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

substantial cost reductions are expected in the coming years[207]. This process will take time and a coordinate effort of National institution and private companies.

So far, on-shore wind only, can be compared with nuclear energy: the cheapest electricity produced from wind is in the USA, ranging from USD 48.39/ MWh to USD 70.47/ MWh. US Generation III+ nuclear reactor can produce electricity at a similar cost.

At the end of the work, main energy topics for Italy will be presented, and try to propose a solution for our concerns.

[207] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 111

IV. G8 COUNTRIES ENERGY MIX

The first two chapters have represented an in depth overview on the most important alternatives energy sources: nuclear, wind and solar power.

Afterwards, I kept on describing relevant features of these energies, from an economic point of view, showing their convenience and which factors can influence their competitiveness. I have demonstrated that nuclear power, although expensive at the beginning[208], is already a self-sustaining source of energy while many renewable energies, such as solar and off-shore wind are not yet competitive in free-markets.

I believe it is fundamental to go through policies of big countries to understand how they face environmental, social and economic aspects of energy.

This chapter is therefore about how the principal economies of the world manage their energy mix and which energy policy they are implementing to face uncertainty deriving from oil dependence.

I will refer to the G8 economies except for Italy, which a conclusive, separate chapter, will be dedicated to.

Starting from each energy mix, I would like to show the relevant energy policies they have been carried on in recent years.

Moreover, I decided to study Italian case apart, because I would like to have a more specific focus on my country, which is experiencing drastic changes in its energy model, and I would try to play as an energy decision maker and suggest some possible modifications to our energy policy.

The following chapter will be, therefore, an analysis of the energy policy of the seven biggest economies: Germany, France, United Kingdom, Japan, Russia, Canada and the US.

[208] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, Paris, p. 61, 2010

4.1 Germany

Only a handful of countries can have such an important impact on global energy policy as Germany. Its large size and strategic position within Europe give it great importance in the economics of the whole world.

Therefore, consequently of the globalization of the markets, German energy policy indirectly influence the entire continent.

At the start of the previous decade, an agreement to phase out nuclear power was reached, one that will culminate with the last reactor shuttered in about 15 years[209].After the recent Fukushima accident, nuclear policy has been re-thought again, and the Government decided to close all the plants by 2020[210], as a consequence to the emotional reactions after the Japanese tragedy.

Losing the nuclear option will have significant impacts on energy security, economic efficiency and environmental sustainability.

Eliminating nuclear from the supply portfolio will reduce supply diversity, increasing reliance on energy imports, particularly natural gas, which is not diversified enough.

Shutting down productive assets before their useful lifetime will also impact economic efficiency, requiring additional near-term investments in new capacity that could otherwise be avoided.

While additional renewable capacity, along with energy efficiency gains, could certainly make up some of the resulting gap, to compensate nuclear absence there will be great reliance on fossil fuels[211].

Without any doubts, a phase-out will limit Germany’s full potential to reduce its emissions.

Germany’s total primary energy supply was 345 Mtoe[212] in 2005. The country has a relatively balanced mix of fuels and oil is the largest share of it, at more than one-third, followed by coal (24%), natural gas (23%) and nuclear (12%).

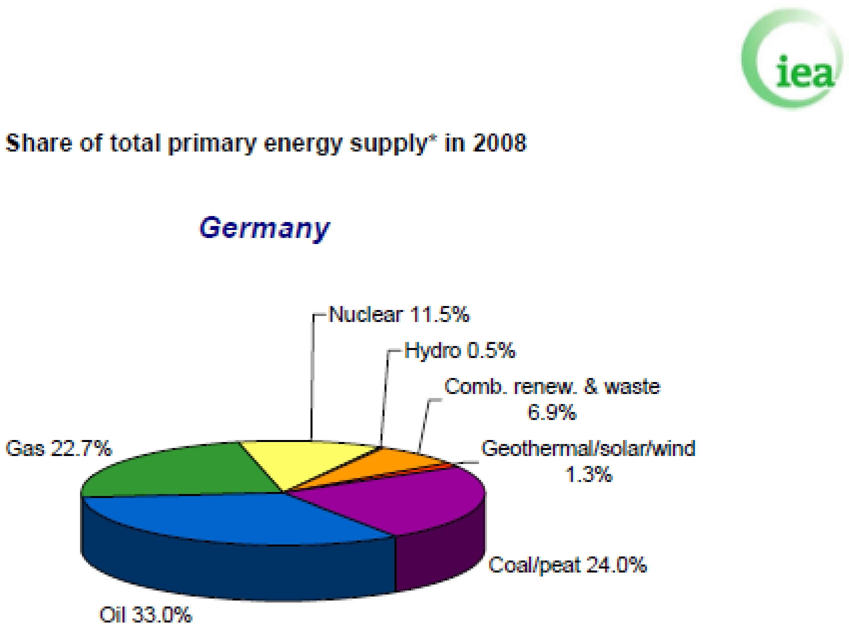
[209] International Energy Agency, Energy policies of IEA countries: Germany Review, p. 11, Paris, 2007
[210] , Nuclear? Nein, danke, *The Economists,* 02 June 2011,
available at http://www.economist.com/node/18774834
[211] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 8, 2007
[212] Million tons of oil equivalent

Compared to other IEA countries, Germany has a very high share of renewable quota and those energies are rapidly increasing thanks to Government incentives[213].

Renewable sources are basically solar power and both types of wind turbines.

They are not yet self sustaining, thus the Government is correctly trying to help their development.

FIGURE 22

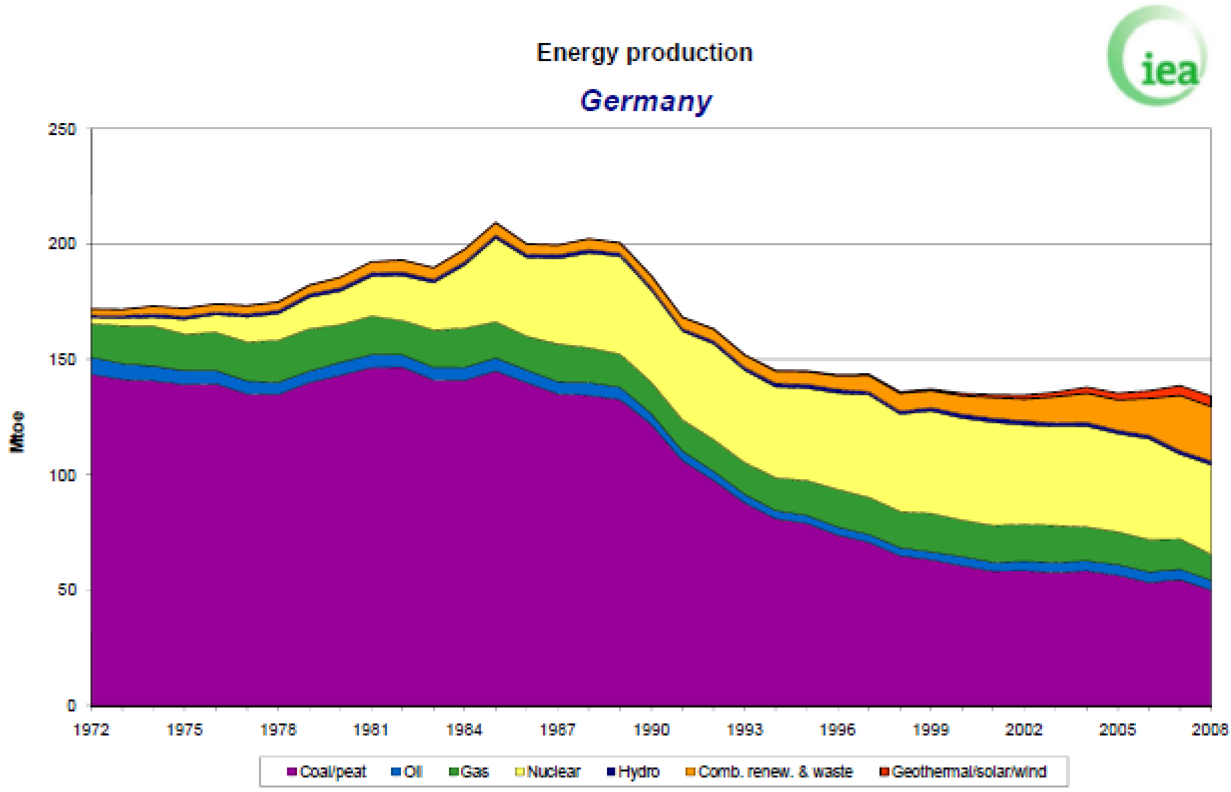


Source: ENERGY POLICIES OF IEA COUNTRIES, GERMANY REVIEW

In addition to nuclear, Germany produces significant amounts of coal, so that in case of a nuclear definitive phase-out, an increase in carbon usage will be encouraged[214].

[213] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 16, 2007
[214] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 16, 2007

FIGURE 23



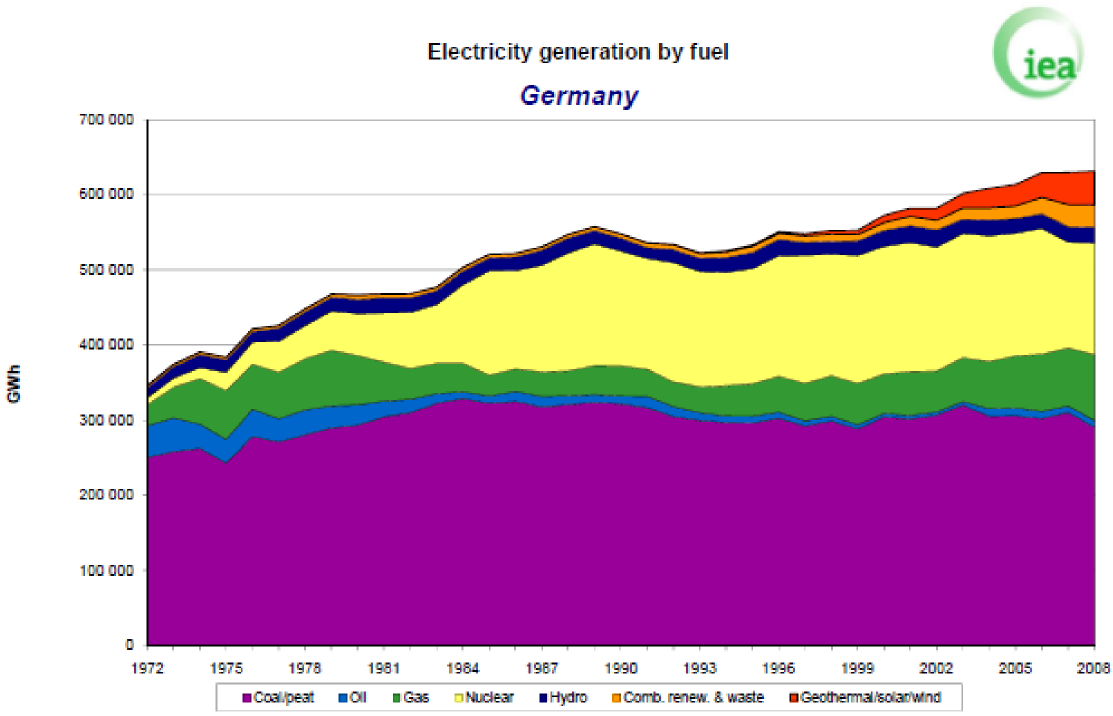
Source: ENERGY POLICIES OF IEA COUNTRIES, GERMANY REVIEW

Concerning the electricity market, the share generated from nuclear is 27%, the same as in 1995. This share has remained steady since the mid-1980s assuring a relative cheap base-load electricity supply.

The largest increase has been in electricity generated from renewable sources which has grown at an average annual rate of 9% since 1995, rising from 3.9% in 1985 to 4.9% in 1995 and to 10.1% in 2005[215].

[215] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 20, 2007

FIGURE 24



Source: ENERGY POLICIES OF IEA COUNTRIES, GERMANY REVIEW

Approximately every five years, the Federal Ministry of Economics and Technology commissions are meant to forecast a long-term energy supply and demand[216]. Independent scientific research institutes provides politicians with data, used for policy guidance. The most recent forecast, which was conducted by the University of Cologne's Institute of Energy Economics, was released in 2005 with projections to 2030.

The new forecasted scenario, is based on a significantly higher oil price trajectory, and the most relevant changes by fuel are foreseen to come from nuclear and renewable energies. Some of the supply coming from nuclear will be offset by growth in renewable supply by 2030[217]; the share of nuclear was supposed to decrease from 13% in 2000 to zero in 2030, partially covered by the increase in the share of renewable and hard coal. The share of gas in Germany will also rise slightly

[216] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 24, 2007
[217] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 21 2007

between 2000 and 2030, from 21.1% to 22.5%, offsetting some of the nuclear phase-out[218].

4.1.1 Nuclear phase-out and perspectives

In 1999, the German government decided to phase out nuclear power in the country. The present Government changed his opinion, the phase out was cancelled in 2009, and each power station is assigned a residual electricity output[219]. When a nuclear power station has generated the agreed output, it must be shut down. So far, two nuclear power stations have been taken off line: Stade (672 MW) in 2004 and Obrigheim (357 MW) in 2005. The eight eldest power plants are supposed to be turned off in the current year. Such a rapid action could damage the grid and create distribution instability, considering that five of them are in the South of the country.
According to a rough estimate, all nuclear power stations in Germany will be out of service by around 2022[220]. Overall, a large part of the German population has strong reservations regarding the continued use of nuclear power in the country. After the recent Fukushima accident, nuclear social acceptance has decreased dramatically. However, according to Eurobarometer, which tracks public opinion in Europe, a significant proportion of those currently opposed to nuclear power would be prepared to accept it in the country's fuel mix if the issue of radioactive waste were solved[221]. A nuclear phase-out will also reduce energy security, reducing the diversity of energy supplies in the country through increased reliance on imports of fossil fuels. In particular, the higher gas needs that will arise from the phase-out will likely result in greater reliance on gas from Gazprom[222], a company that already supplies over a third of Germany's imported gas, further reducing the country's supply diversity. Furthermore, the closure of several nuclear plants in the southern part of the country will exacerbate the congestion on north-south transmission lines.

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[218] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 21 2007
[219] World Nuclear Association, Germany Country Profile, 2011
[220] Associazione Italiana Nucleare, Uscita anticipata dal nucleare: per la Germania aumento delle bollette di 32 miliardi e disoccupazione in aumento, September 01, 2011
[221] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 27, 2007
[222] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 154, 2007

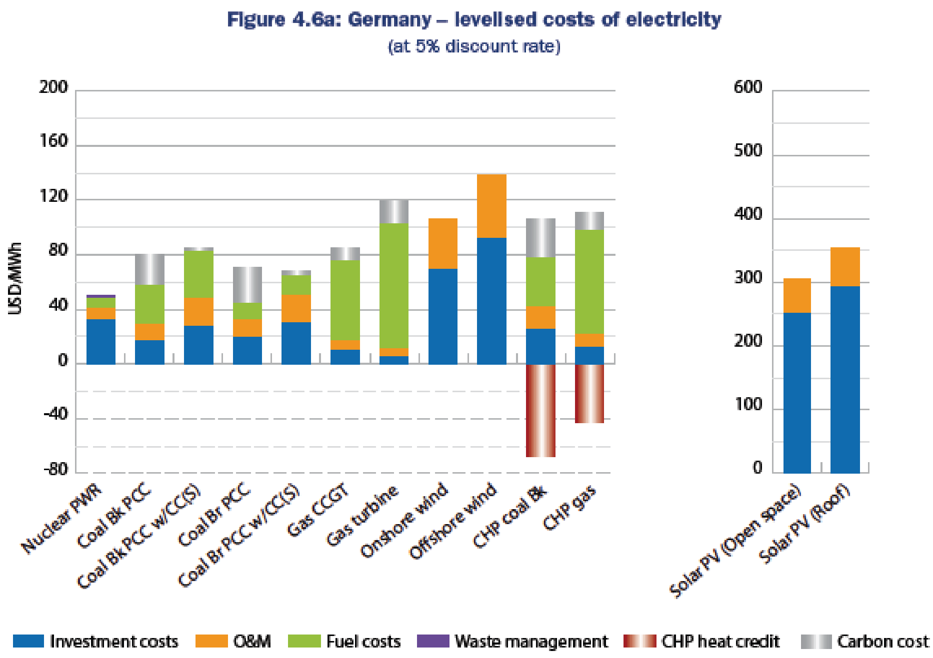
Germany works to promote renewable energies which, in nuclear absence, will play a key role in climate change. The government has taken on renewable specific targets and objectives:

- increase the share of renewable energy in electricity generation to at least 20% by 2020
- increase the share of renewable energy in total production to at least 10% by 2020[223].

There is now a substantial renewable energy industry in Germany. More than 200 000 people work in the field, of which 35 000 work in the solar sector[224].

The costs of different electricity generations are provided by the Electricity Generation Costs expert group, which has figured out different costs level depending on the discount rate of the project[225].

FIGURE 25



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

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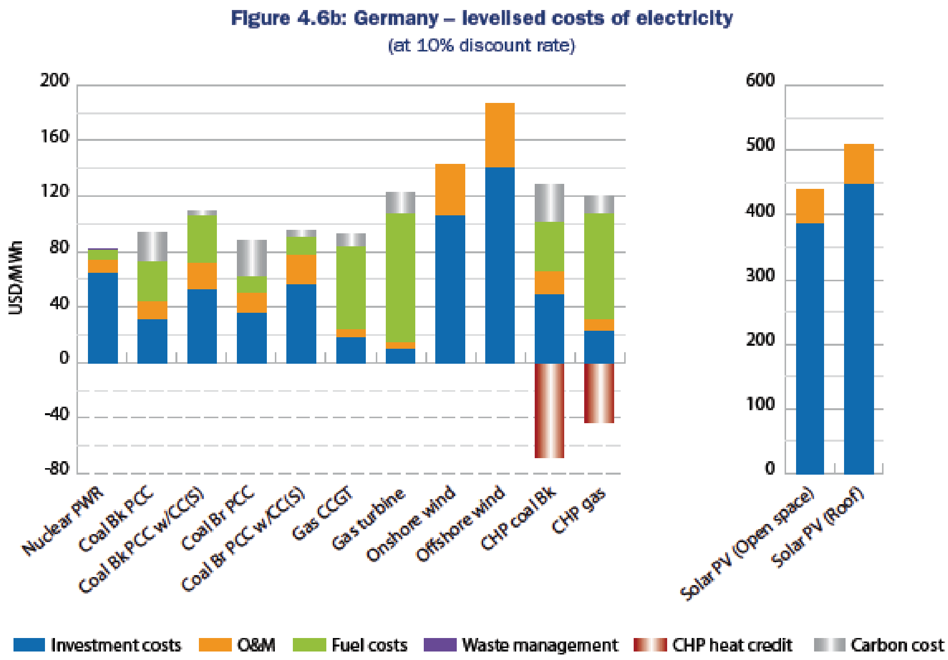
223 International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 154, 2007

224 Data of 2007

225 International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, p. 33, Paris, 2010

FIGURE 26



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

Both at a 5% and 10% discount rate, nuclear is comfortably the cheapest electricity source in Germany. Coal and gas turbine look like the only competitors right now. Solar power is at both discount rate out of the market; this technology must be improved to perform on an industry base. The same for offshore wind turbines[226], which Germany should focus on, like every northern country, given its high potential.

At the moment, the most efficient type of renewable energy is on-shore wind, but its price in the country range from a back end of USD105.81/MWh at a 5% discount rate calculation, to a front level of USD 142.96/MWh at a 10% rate.

To give evidence of the higher competitiveness of nuclear, with respect to electricity production, it is enough to report that its cost ranges from USD 49/MWh to USD 82.64/MWh.

Although the recent Japanese accident is influencing energy policy all over the world, it is still important to mention the International Energy Agency's recommendation on energy policy, given to Germany in 2007:

[226] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 56 , 2010

- reconsider the nuclear phase-out in light of its likely negative environmental, security of supply and economic effects.
- initiate a national debate on the future role of nuclear power in the energy mix, starting with whether the operating lifetimes of existing plants should be extended to better accommodate energy and environmental policy objectives.
- adhere to the commitment to decide on a way forward on radioactive waste disposal within the lifetime of the present parliament and establish a legal framework to accomplish this[227].

4.2 United States of America

The United States is dependent on fossil fuels for almost all its energy supply. It is fully self-sufficient in coal and largely self-sufficient in natural gas, with about a fifth of gas supplied by imports from North American neighbors[228]. Because of the high demand for oil, however, the United States is heavily dependent on oil imports, and the import dependence has increased since 1990 to reach over 50% in 2005.

FIGURE 27

Table 1

Share of TPES Provided by Indigenous Production by Fuel, 1990 to 2030

	Share (%)					Change (%)	
Fuel	1990	2005	2010	2020	2030	2005/1990	2020/2005
Coal	118	102	101	97	96	-14	-5
Oil	56	34	40	37	32	-40	10
Gas	95	83	81	80	79	-13	-4
Import dependence	16	30	28	30	32	86	-1

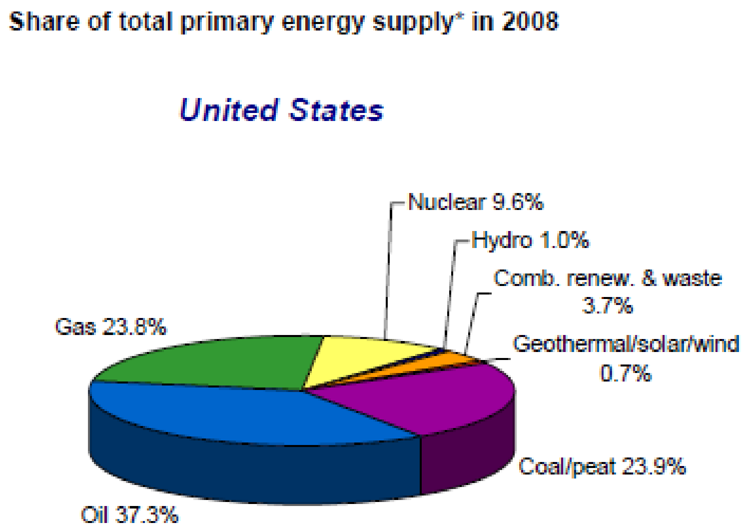
Sources: *Energy Balances of OECD Countries*, IEA/OECD Paris, 2007 and country submission.

Source: ENERGY POLICIES OF IEA COUNTRIES, THE UNITED STATES REVIEW

[227] International Energy Agency, Energy policies of IEA countries: Germany Review, cit., p. 147, 2007
[228] International Energy Agency, Energy policies of IEA countries: the United States of America Review, p. 15, Paris, 2007

Energy demand is increasing in all sectors of the economy, but is primarily driven by increases in the transport and residential sectors. Electricity demand in particular is increasing rapidly in the residential and commercial sectors, and can therefore be expected to become more variable[229].

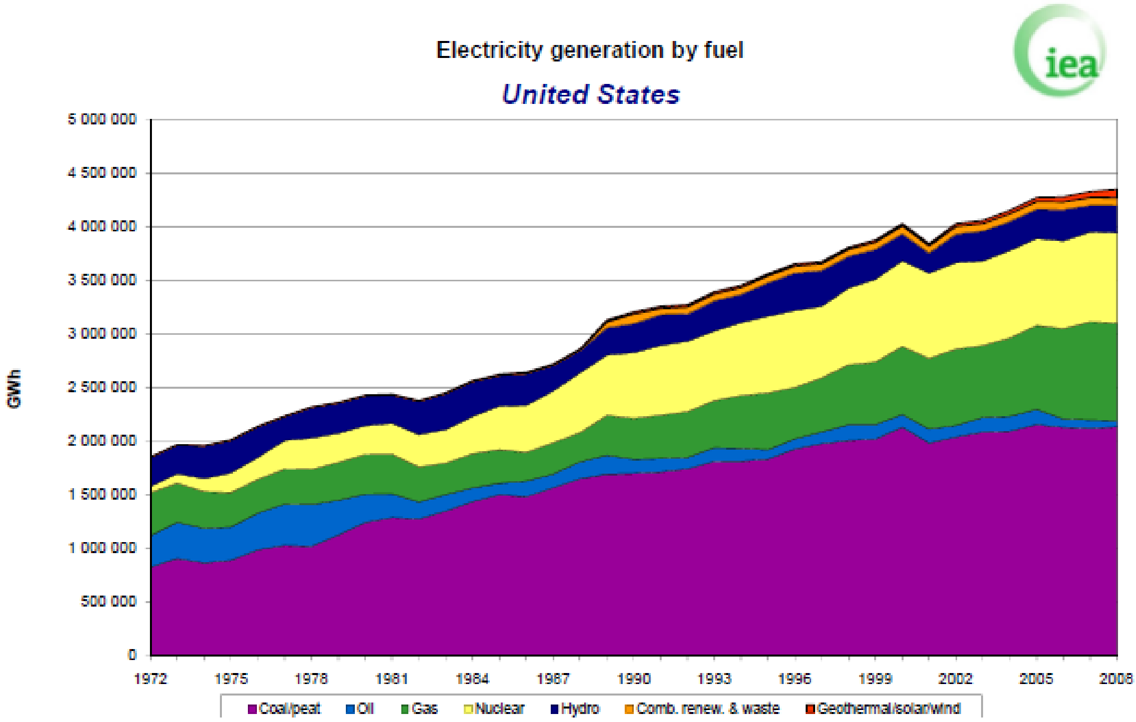
FIGURE 28



Source: ENERGY POLICIES OF IEA COUNTRIES, THE UNITED STATES REVIEW

[229] International Energy Agency, Energy policies of IEA countries: the United States of America Review, cit. p. 15, 2007

FIGURE 29



Source: ENERGY POLICIES OF IEA COUNTRIES, THE UNITED STATES REVIEW

Total primary energy supply in the USA has steadily increased since the beginning of the Seventies', across all energy sources. In the last 30 years, energy supplied from coal almost doubled to 554 Mtoe[230]; oil rose by 30% to 957 Mtoe, natural gas increased by 4% to 538 Mtoe.

Nuclear supply increased from 11 Mtoe to 218 Mtoe; the large increase is in the renewable sources, almost 150% so far, with a 85 Mtoe[231]. Given that hydropower declined by around 7%, the rise in renewable energies is mainly supported by on-shore wind and biomass and waste[232].

[230] 1 Mtoe = million tonnes of oil equinalent

[231] International Energy Agency, Energy Technology Perspectives, p.9, Paris, 2010

[232] Data refers to the period 1971-2007

4.2.1 Energy policies

The USA Government energy policy can be summed up in main points:

- Diversify energy supply by promoting alternative and renewable sources of energy, encouraging the expansion of nuclear energy in a safe and secure manner
- increasing domestic production of conventional fuels, and investing in science and technology
- increase energy efficiency and conservation in homes and businesses
- expand the Strategic Petroleum Reserve[233].

To achieve this, the focus is on strengthen energy infrastructure, promote energy efficiency, expand the use of renewable energy, and boost the domestic production of conventional fuels. But the USA also need to fortify their strategic position in the Middle-East to guarantee a medium-term oil supply.

Some of the more notable policy measures are provided by the Energy Policy Act of 2005[234]:

- tax incentives for the purchase of efficient appliances and equipment.
- tax incentives for the purchase of fuel-efficient hybrid and diesel vehicles.
- production tax credits of USD 0.018/kWh for 6000 MW of new nuclear capacity for the first eight years of operation[235][236]. Extension of existing tax

[233] International Energy Agency, Energy policies of IEA countries: the United States of America Review, cit , p. 18, 2007
[234] International Energy Agency, Energy policies of IEA countries: the United States of America Review, cit, p. 20, Paris, 2007
[235] Data refers to 2007
[236] These will be allocated pro-rata to companies which begin the construction before the end of 2013, and which will enter operation before the end of 2020[236]

credit for production of electricity from wind, biomass and landfill gas, with a new credit for residential solar systems

- an R&D program for methane hydrates, a potentially large new source of natural gas.

As demonstrated by the measures reported below, the American Government had the intent to promote alternative energy sources, to reduce the dependence on traditional fossil fuels.

Both nuclear and renewable energies contribute to this purpose; the current Government has not thought about a nuclear phase-out, not even after the Japanese accident.

4.2.2 Renewable energies projections

Renewable energy market has been experiencing a rapid growth in recent years due to a mix of rapidly rising prices for fossil fuels since 2004, deeper environmental concerns, increased hydro availability and wider support policies[237].

Renewable electricity generation accounted for 9% in 2008[238], with the leading capacity of hydroelectric. Wind has expanded rapidly, it is available through all the country, but mainly in the northern part[239].

Renewable fuel use is still growing rapidly, as outlined by the Energy Information Administration in his 2011 outlook[240]. As shown by the graph below, renewable energy sources are leading rise in primary energy consumption

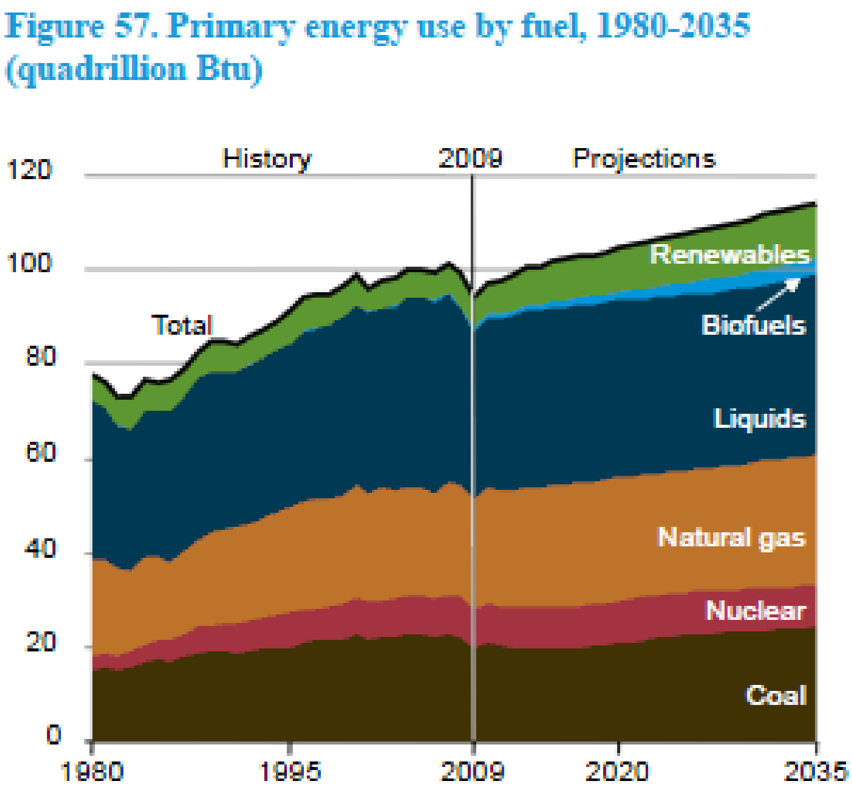
[237] International Energy Agency, Energy policies of IEA countries: the United States of America Review, cit. p. 15, 2007

[238] International Energy Agency, Energy Technology Perspectives, cit., p 349, 2010

[239] International Energy Agency, Energy Technology Perspectives, cit., p 349, 2010

[240] Energy Information Administration, Annual Energy Outlook, p. 63, Washington, 2011

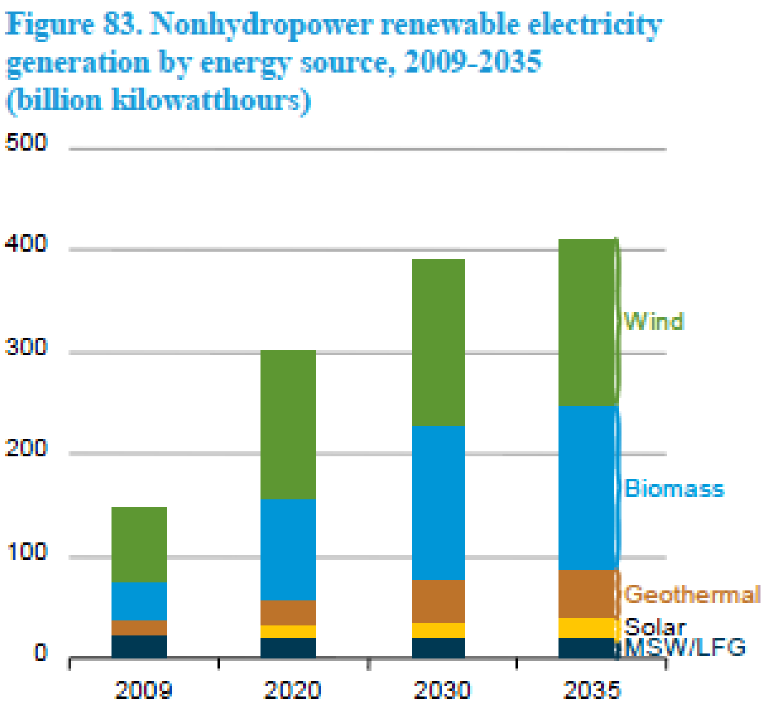
FIGURE 30



Source: EIA ANNUAL ENERGY OUTLOOK 2011

The renewable share of total energy use increases from 8 percent in 2009 to 13 percent in 2035.

FIGURE 31



Source: EIA ANNUAL ENERGY OUTLOOK 2011

Renewable electricity generation, excluding hydropower, will account for nearly one-quarter of the growth in electricity generation from 2009 to 2035,according to the forecasts of the US Energy Information Administration.

Following the projection, in 20 years generation from wind power nearly doubles its share of total generation, while generation from geothermal resources triples as a result of technology advances that make previously marginal sites attractive for development, as well as increasing the resources available at existing geothermal sites[241].

Renewable electricity generation in the end-use sectors also continues to grow.

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[241] International Energy Agency, Energy policies of IEA countries: the United States of America Review, cit , p. 76, 2007

There is an attractive opportunity to use waste heat from bio fuels production, to generate electricity in the US. Consequently, in this perspective, generation from biomass more than triples from 2009 to 2035, when it accounts for 39 percent of total non hydroelectric renewable electricity generation[242].

Generation from solar resources increases from 2 percent of non hydroelectric renewable generation in 2009 to more than 5 percent in 2035, as capital costs, especially for photovoltaic technologies in the end-use sectors, are expected to decrease over time.

End-use solar generation grows from 2.3 billion KWh in 2009 to 16.8 billion KWh in 2035, and additional growth in solar generation comes from utility-scale PV plants, which begin to become competitive in the later years of the projection.

4.2.3 Nuclear energy

The USA is the world's largest producer of nuclear power, accounting for more than 30% of worldwide nuclear generation of electricity. The country's 104 nuclear reactors produced 799 billion kWh in 2009, over 20% of total electrical output[243].

The USA has 104 nuclear power reactors in 31 states, operated by 30 different power companies. The US nuclear power industry has undergone significant consolidation in recent years, driven largely by economies of scale, deregulation of electricity prices and the increasing attractiveness of nuclear power relative to fossil generation. the top 10 utilities account for more than 70% of total nuclear capacity. The consolidation has come about through mergers of utility companies as well as purchases of reactors by companies wishing to grow their nuclear capacity. Operators in nuclear plants are nowadays 25[244].

Nuclear power capacity is meant to expand by 9.5 GW, from 101 GW in 2009 to 110.5 GW in 2035, but the nuclear share of primary energy falls from 8.8 percent in 2009 to 8.0 percent in the provisions for the 2035[245].

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[242] Energy Information Administration, Annual Energy Outlook, cit, p. 63, 2011
[243] World Nuclear Association, the USA Country Profile, 2011
[244] World Nuclear Association, the USA Country Profile, 2011
[245] Energy Information Administration, Annual Energy Outlook, cit, p. 63, 2011

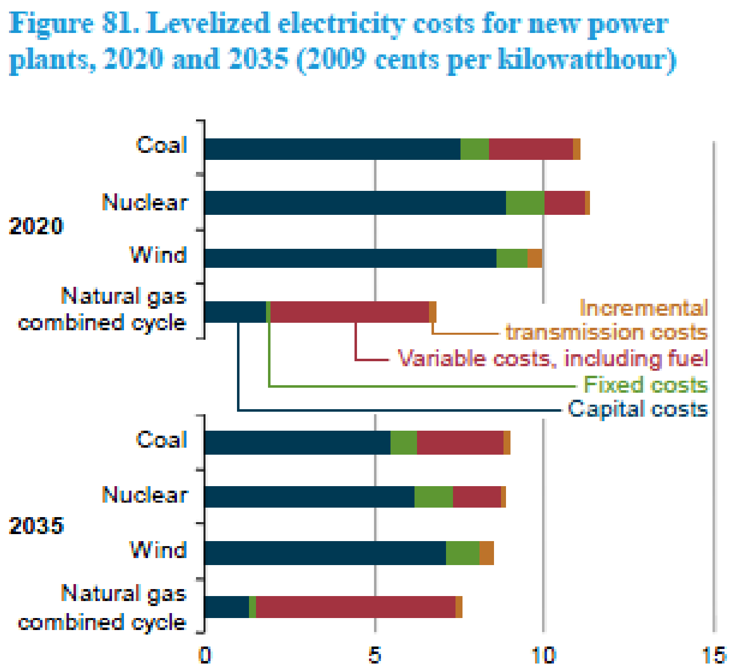
In the projections, nuclear power capacity increases, including 3.8 GW of expansion at existing plants and 6.3 GW of new capacity.

High construction costs for nuclear plants, especially relative to natural-gas-fired plants, make other options for new nuclear capacity uneconomical even in the alternative electricity demand and fuel price cases.

4.2.4 Electricity costs

Concerning electricity costs projections, nuclear LCOE is supposed to be higher than wind's, until 2020. This is of course due to the great capital expenditure that nuclear required for new plant construction. Afterwards, when fixed costs are repaid, a typical nuclear plant will operate with low expenditure, thus having a high percentage of profits. In fact, up to 2035, nuclear LCOE will stabilize at a lower level.

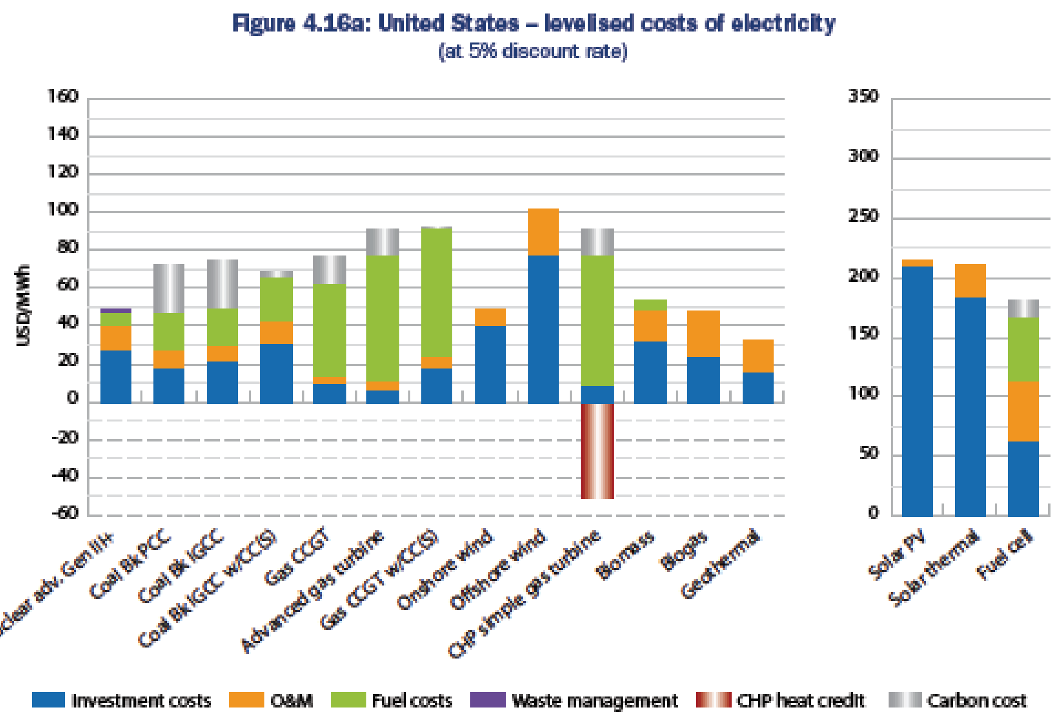
FIGURE 32



Source: EIA ANNUAL ENERGY OUTLOOK 2011

The LCOE for nuclear is on average ranging between USD 48.73 MWh at a 5% dicount rate, and USD 77.39/MWh at a 10% discount rate. On-shore wind is effectivecly cheaper than nuclear because its LCOE is USD 48.39 MWh at a 5% dicount rate, and USD 77.47/MWh at a 10% discount rate[246]. Other competitive types of renewables sources are geotermal , biomasand biogas, depending on the interest rate used for calculations. Their share in total electricity poduced is the 3%, against a consolidated 10% of nuclear and hydro.

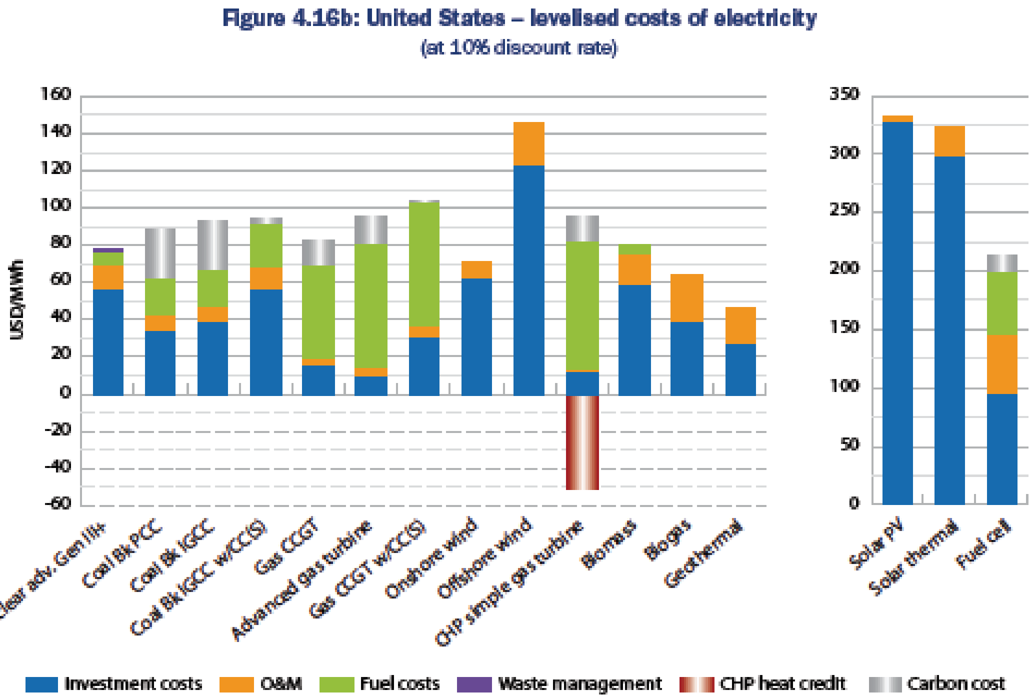
FIGURE 33



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

[246] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 62

FIGURE 34



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

One nuclear unit, Oyster Creek, is expected to be retired at the end of 2019, as announced by Exelon in December 2010[247].

With costs for natural-gas-fired generation rising and future regulation of pollutant emissions uncertain, the economics of keeping existing nuclear power plants in operation are favourable.

[247] Energy Information Administration, Annual Energy Outlook, cit, p. 63, 2011

4.3 Canada

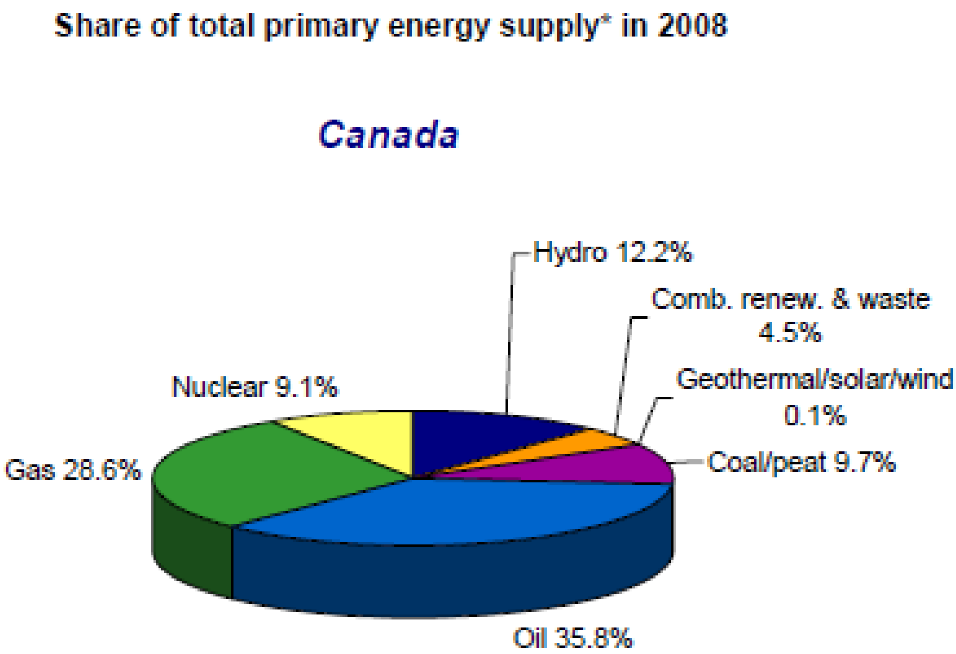
Canada enjoys the advantage of a diverse and balanced portfolio of energy resources and is one of IEA's largest producers and exporters of energy. The importance of the energy sector for the Canadian economy, and for global energy security, has grown steadily over the last decade. The country's abundant resource base has the potential to deliver even great volumes of energy[248].

Nonetheless, like other energy-producing economies, Canada faces the sustainability challenge;

Canada has higher energy intensity, adjusted for purchasing power parity[249]. On the other hand, the Canadian power sector is one of the lowest emitting generation portfolios, producing over three-quarters of its electricity from renewable energy sources and nuclear energy combined[250].

Canada is committed to working to improve and increase energy efficiency.

FIGURE 35



Source: ENERGY POLICIES OF IEA COUNTRIES, CANADA REVIEW

[248] International Energy Agency, Energy policies of IEA countries: Canada Review, p. 25, Paris 2010
[249] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 65, 2010
[250] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 9, 2010

4.3.1 The importance of hydropower

Canada, one of the largest and geographically diverse OECD member countries, possesses substantial renewable energy, as shown in the graph above, including hydropower, biomass, and wind, solar, geothermal and ocean energy.

The 16.1% of the total primary energy supply of Canada came from renewable sources, in 2008[251].

This good performance on renewable energies depends largely on hydropower. Canada is the OECD's largest producer of electricity from hydropower, but rests among the lowest in the OECD in terms of non-hydro renewable energies, with wind and solid biomass the only other sources of note.

Hydropower contributed 372.5 GWh to electricity production in 2008[252].

In 2007, almost 62% of Canada's electricity generating capacity came from renewable energy, of which hydropower accounted for 57.6% (73.4 GW), wind energy represented 0.5% (1.8 GW) and solid biomass accounted for 1.3% (1.6 GW).

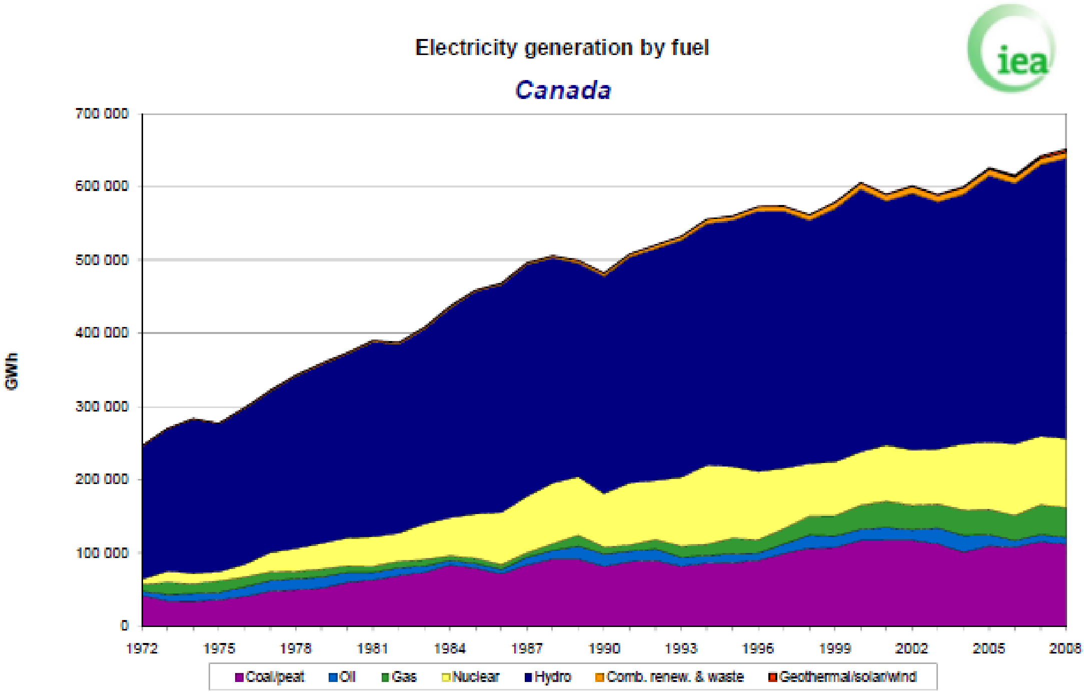
Solar photovoltaic (26 MW) and tidal energy (20 MW) represented a very small portion of Canada's electricity capacity[253].

[251] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 85, 2010

[252] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 85, 2010

[253] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 85, 2010

FIGURE 36



Source: ENERGY POLICIES OF IEA COUNTRIES, CANADA REVIEW

The federal government has instituted a number of incentives such as:

- wind Power Production Incentive

- market Incentive Program for Distributors of Emerging Renewable Electricity Sources[254].

Moreover, the International Energy Agency suggested to develop a long-term policy for the future of renewable energy to Canada, integrating it into an overall energy strategy.

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[254] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 88, 2010

This strategy must take into account the geographic, geological and resource differences between the provinces and territories:

- commit to the long-term, effective and predictable support mechanisms in order to provide developers and investors with a stable regulatory framework
- develop more ambitious programs to facilitate the use of renewable electricity generation, micro-generation and heating in geographically isolated regions in order to offer an alternative to the consumption of petroleum products[255].

4.3.2 Nuclear Energy

Canada is a pioneer of nuclear energy, having developed its own pressurized heavy water reactor. In 2008, nuclear generating capacity of 12.5 GW provided Canada with 15% of its electricity (89 TWh).

The country is also one of the world's largest uranium producers, from mines in northern Saskatchewan[256].

The great majority of nuclear capacity is in Ontario, with 16 reactors in operation at present and two others under refurbishment. New nuclear plants have been proposed in Ontario, Alberta, Saskatchewan and New Brunswick[257].

The International Energy Agency in his report on the country dated 2009, provides support and encouragement for the deployment of new nuclear capacity in those provinces which decide to pursue nuclear programs, especially those planning to host their first nuclear plants, maintaining vital nuclear R&D and radioactive waste management activities, in particular to support the refurbishment and improved operation of the existing nuclear fleet[258].

[255] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 100, 2010
[256] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 221, 2010
[257] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 221, 2010
[258] International Energy Agency, Energy policies of IEA countries: Canada Review, cit. p. 224, 2010

4.3.3 Electricity costs

FIGURE 37

Figure 4.3a: Canada – levelised costs of electricity
(at 5% discount rate)

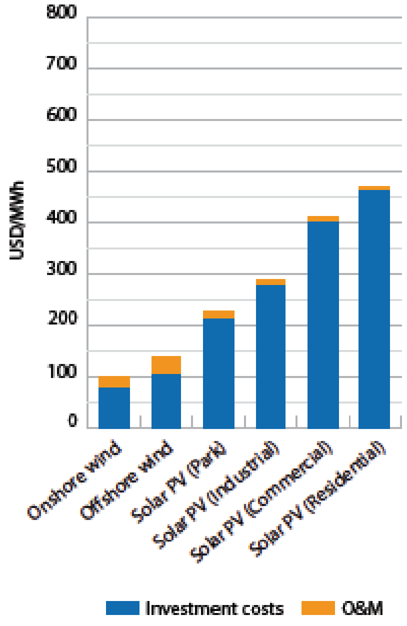
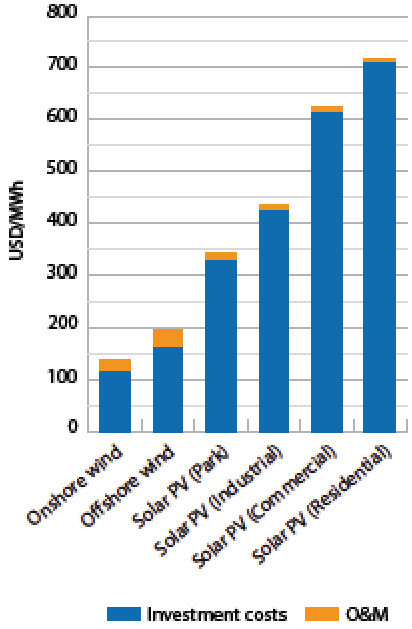


Figure 4.3b: Canada – levelised costs of electricity
(at 10% discount rate)



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

As shown by the graph above, data about nuclear energy and hydropower LCOE are not provided.

However, it still interesting to see how costs of on-shore wind are not yet competivite compared to an average costs of nuclear energy.

Assuming the American LCOE for nuclear for comparison[259], that is on average ranging between USD 48.73/MWh at a 5% dicount rate, and USD 77.39/MWh at a 10% discount rate, on shore wind costs of electricity is almost double in Canada, ranging from USD 99.42/MWh at a 5% dicount rate to USD 139.23/MWh at a 10% discount rate calculation.

This is maybe due to the policy of expoliting only the enormous amount of hydro potential of the country, leaving apart others renewble energies. But in recent years

[259] It might be reasonable the LCOE for nuclear is similar in the US and in Canada

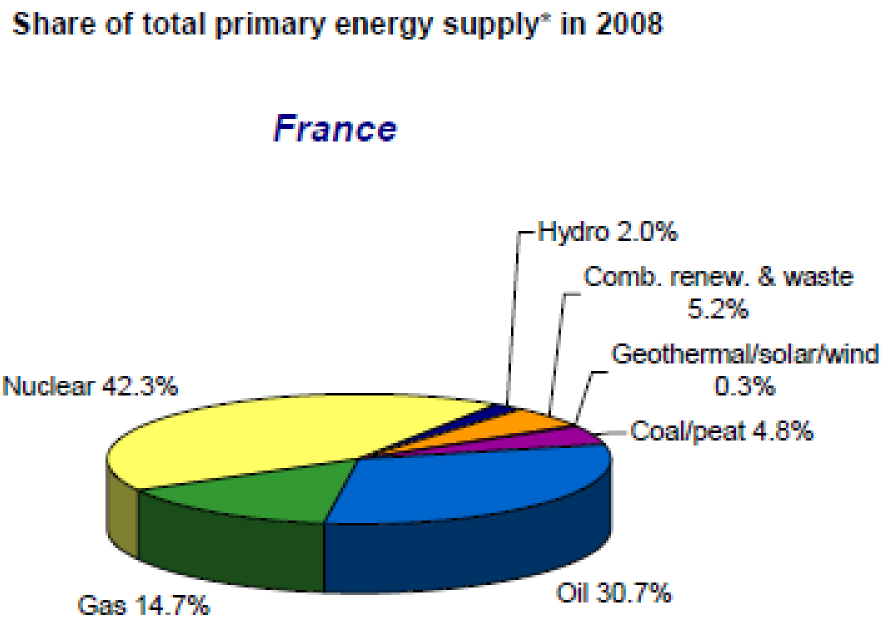
the deployment of wind is improving, given the amazing resources of the country. The price is thus expected to become more competitve in some years.

4.4 France

France's energy policy is one of the most extreme in Europe, given the high penetration of nuclear power, and it is increasingly adapting to global energy and climate challenges.

In 2008, nuclear power accounted for nearly 80% of France's electricity generation and over 40% of total primary energy supply[260].

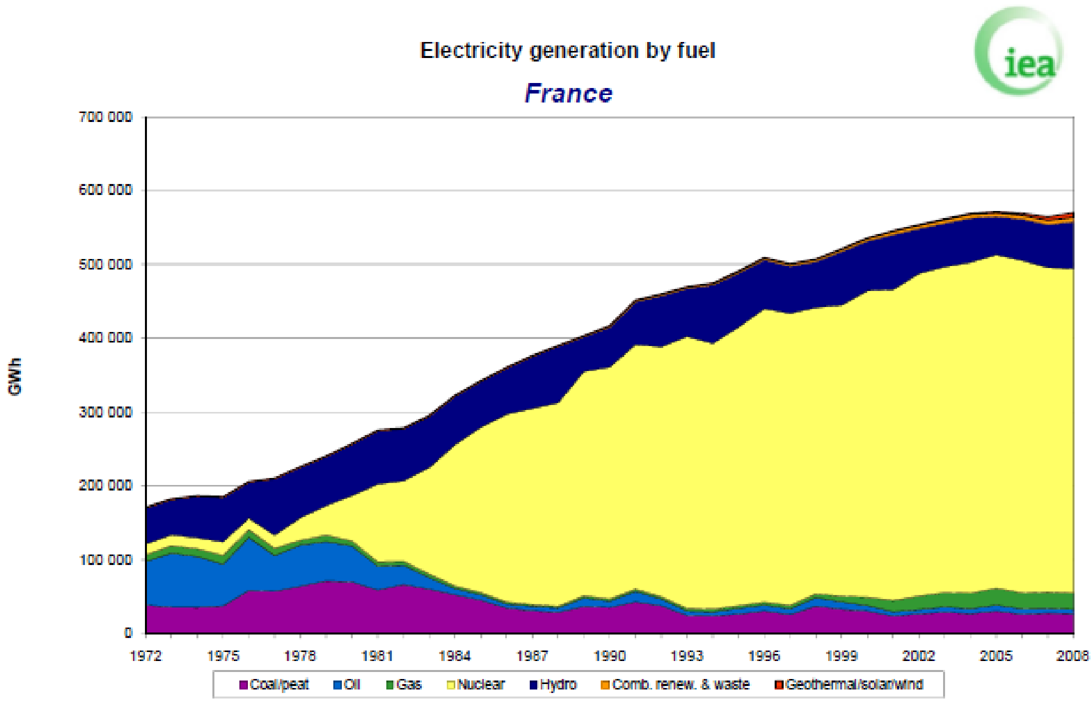
FIGURE 38



Source: ENERGY POLICIES OF IEA COUNTRIES, FRANCE REVIEW

[260] International Energy Agency, Energy policies of IEA countries: France Review, Paris, p. 7, 2009

FIGURE 39



Source: ENERGY POLICIES OF IEA COUNTRIES, FRANCE REVIEW

France imports nearly all of its oil, gas and coal requirements, but its fossil fuel imports are well diversified.

The French government fixed goals and targets aimed at combating climate change are very ambitious:

– 75% reduction in CO2 emissions by 2050
– a reduction in GHG emissions in the transport sector to 1990 levels by 2020[261].

The government needs to address the coexistence of regulated tariffs and market prices in the electricity sector which may impede investment in new capacity and prove to be an obstacle to market liberalisation.

[261] International Energy Agency, Energy policies of IEA countries: France Review, cit., p. 7, 2009

4.4.1 Nuclear relevance

France has a fleet of 58 pressurized water reactors on 19 different sites providing for 63GW of installed capacity[262]. They were all built in the period from 1977-1996. The capacity of individual units range from 900MW and 1450MW, with an expected life of 23 years.

The transition to a more competitive market in France has been challenging because of the regulated tariffs. While the generation and retail sectors are fully open to competition, in line with EU directives, competition is rather limited[263].

Although nuclear development is not without challenges, there has been a renewed interest in nuclear among IEA member countries, partially impeded by disaster of Fukushima. Nuclear technology is currently, apart from hydropower, the only large-scale, base load, electricity source with a low carbon footprint.

France's massive production of nuclear base-load electricity and its historic overcapacity have made it a natural exporter of base load energy to its European neighbors in the past.

The French government, however, should clarify its position on the contribution of nuclear power exports to the emerging European electricity market.

The French government's decisions regarding future market reform in the electricity sector could provide a valuable lesson for other countries.

The French government should also continue to strengthen efforts in international co-operation, both at the European and at the global levels, with special attention to countries that are considering or reconsidering the nuclear option[264], to enable nuclear power to be part of a global diversification of energy sources and long-term actions to limit GHG emissions[265].

France's vast experience and expertise with nuclear power provides an opportunity for the government to take the lead on setting sound and sustainable policies for radioactive waste management.

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[262] Data of 2008

[263] International Energy Agency, Energy policies of IEA countries: France Review, cit., p. 9, 2009

[264] International Energy Agency, Energy policies of IEA countries: France Review, cit., p.10, 2009

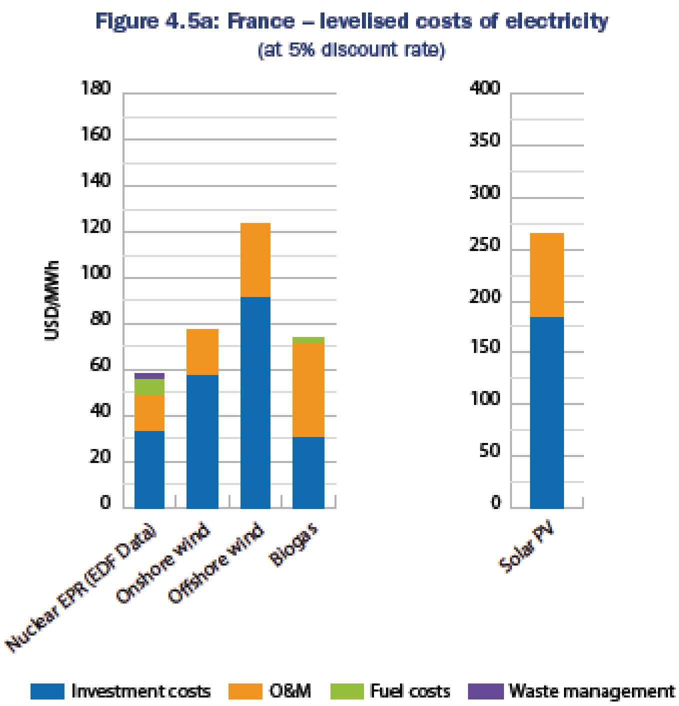
[265] International Energy Agency, Energy policies of IEA countries: France Review, cit., p.10, 2009

4.4.2 Electricity price

Current costs of nuclear power in France are significantly below European wholesale market prices and have the ability to generate substantial profits[266].

So far, the French government managed the issue by requiring Electricité de France to offer electricity to retail customers at a regulated tariff, covering full costs, which for most of the past years was substantially below prices in neighbouring countries.

FIGURE 40



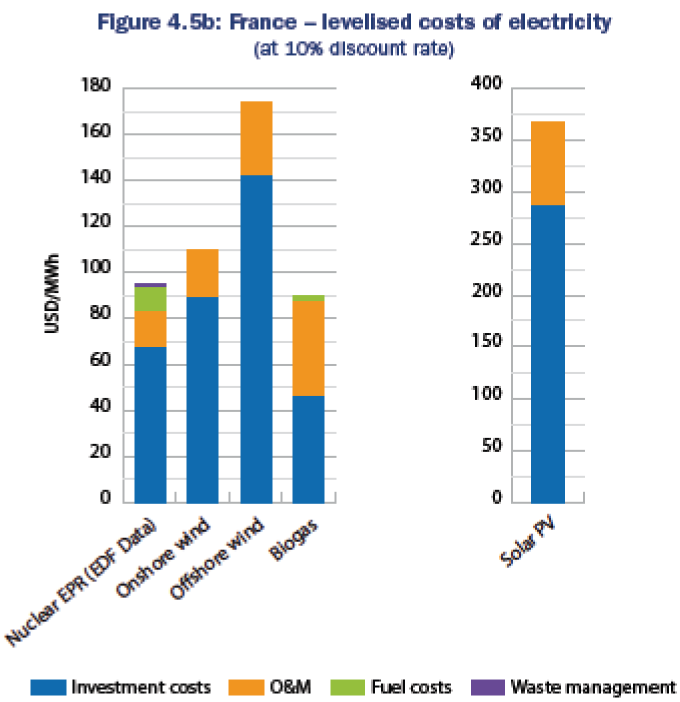
Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

As shown by the graph above, nuclear energy LCOE is comfortably cheaper than other renewable sources. Nuclear price ranges from USD 56.42/MWh at a 5% dicount rate, and USD 92.38/MWh at a 10% discount rate[267].

[266] International Energy Agency, Energy policies of IEA countries: France Review, cit., p. 126, 2009

[267] The costs reported refer to the EPR in Flamanville (EDF data), so it is site specific

FIGURE 41



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

The situation on the French electricity market is complicated by the existence of the so-called transitional regulated market adjustment tariff for industrial customers, which is set below the wholesale market price[268].

It is questionable whether the current tariff structure is sustainable. It may pose a threat to organising the substantial medium-term investments needed for maintenance and life extensions of the nuclear park, and the substantial long term investments needed for the renewal and expansion of France's reactor fleet[269].

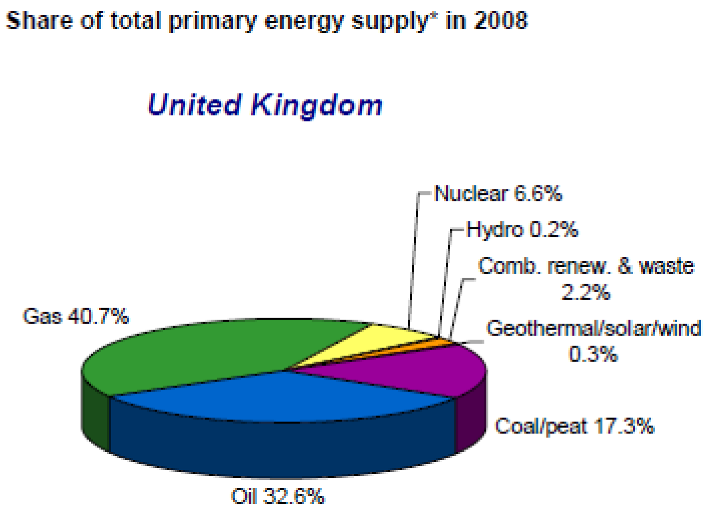
The government is slowly trying to support production from renewable sources.

[268] International Energy Agency, Energy policies of IEA countries: France Review, cit., p. 9, 2009
[269] International Energy Agency, Energy policies of IEA countries: France Review, cit., p. 131, 2009

4.5 United Kingdom

Natural gas and oil are the UK's dominant primary fuels, accounting in 2008[270] for 40.7% and 32.6% of TPES, respectively. These are followed by coal (17.3%), nuclear (6.6%), biomass (2.2%), hydropower (0.2%), wind and solar (0.3).

FIGURE 42



Source: ENERGY POLICIES OF IEA COUNTRIES, UK REVIEW

The major fuel supply trend of the last 30 years has been the rise in the share of natural gas at the expense of coal and oil and the Department of energy and climate change is concerned with that[271].

4.5.1 Renewable sources and nuclear power

The UK has modest natural resources for hydropower, biomass or solar energy although it does have an excellent wind profile and a long coastline for wave and

[270] More recent data are not provided by the IEA

[271] International Energy Agency, Energy policies of IEA countries: United Kingdom Review, p. 24, Paris 2004

tidal energy[272]. This Government is committed to being the greenest Government ever, which includes a firm commitment to renewable energy.

It will seek to increase the target for energy from renewable sources, subject to the advice of the Climate Change Committee.

The UK has been blessed with a wealth of potential renewable energy resources, both on and offshore. The United Kingdom has put in place appropriate financial incentives to bring forward the take-up of renewable sector in the country and the current Government is publishing a renewable delivery plan, to drive faster deployment through the decade[273].

Concerning nuclear power, there are 19 units in operation in the United Kingdom in 8 different locations, combined capacity of almost 9,000 megawatts which are operated by British Energy, the largest electricity generator of the country[274].

The nuclear units in operation in the UK were commissioned between 1965 and1988, the most which are ‘advanced gas-cooled reactors[275], and the newest, named Sizewell B, is a pressurized water reactor[276].

Fleet availability has been improving and, as a result, nuclear electricity generation has increased in the last ten years while its share of total generation has remained stable.

The Government is committed to improve all low-carbon energy generation, thus it is working to ensure that there is a supply chain and skills base in place to enable new nuclear to happen and ensure that the UK benefits from this activity, and it is clear that new nuclear can go ahead so long as there is no public subsidy[277].

It is interesting to mention that a mechanism for letting people choose for locations of new nuclear power plants is provided[278], thus improving the knowledge and nuclear social acceptance.

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[272] International Energy Agency, Energy policies of IEA countries: United Kingdom Review, cit., p. 93
[273] Department of energy and climate change, Annual Energy Statement, London, 2010.
[274] British Energy website. Available at http://www.british-energy.com/
[275] International Energy Agency, Energy policies of IEA countries: United Kingdom Review, cit., p. 155
[276] British Energy website, cit.
[277] Department of energy and climate change, Annual Energy Statement, cit., p. 17, 2010
[278] British Energy website, cit.

4.6 Japan

4.6.1 Country overview

Japan's total primary energy supply was nearly 530 Mtoe in 2006, its energy mix is well-diversified: oil supplies the largest share although its share of total energy consumption has declined from about 80 percent in the 1970s to 46 percent in 2009. Coal continues to account for a significant share of total energy consumption, although natural gas and nuclear power are increasingly important sources.

Natural gas and nuclear energy compose the 15% each of the total primary energy supply[279].

In total renewable energies account for the 3.2% and he energy demand is made of 40% of all consumption in the industrial sector, 26% of transport sector.

The residential sector accounts for the 14% and the remaining 20% is the commercial sector[280]. Japan has few domestic energy resources and is only 16 percent energy self-sufficient. It is the third largest oil consumer in the world behind the United States and China and the third-largest net importer of crude oil. It is the world's largest importer of both liquefied natural gas and coal[281].

Energy security issues are more critical for Japan than for most IEA countries due to its geographical location and limited domestic energy resources.

For the purpose of ensuring security of supply, policies to promote nuclear power and renewable energies further contribute to diversification.

Despite this effort to become energetically independent, however, growing dependency on imported oil from the Middle East is still a concern.

In light of the country's lack of sufficient domestic hydrocarbon resources, Japanese energy companies have actively pursued participation in upstream oil and natural gas projects overseas and provide engineering, construction[282], financial, and project management services for energy projects around the world.

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[279] International Energy Agency, Energy Policies of IEA Countries, Japan, p. 18, Paris, 2008
[280] International Energy Agency, Energy Policies of IEA Countries, Japan, cit, p. 18
[281] US Energy Information Administration, Country Analysis: Japan, 2011
[282] International Energy Agency, Energy Policies of IEA Countries, Japan, p. 18, Paris, 2008

Concerning renewable energies, Japan focuses on the development of the technology, both for domestic use and for export, in fact, the country, despite having great potential (it has the second largest amount of installed solar photovoltaic capacity in the world and it is the largest producer of solar panels), it has a relatively small share of renewable energies in its supply mix[283][284].

On March 11, 2011, a 9.0 magnitude earthquake struck off the coast of Sendai, Japan, followed by a large tsunami. The earthquake and ensuing damage resulted in a shutdown of 6800 MWe of electric generating capacity at four nuclear power stations that have a total capacity of 12000 MWe.

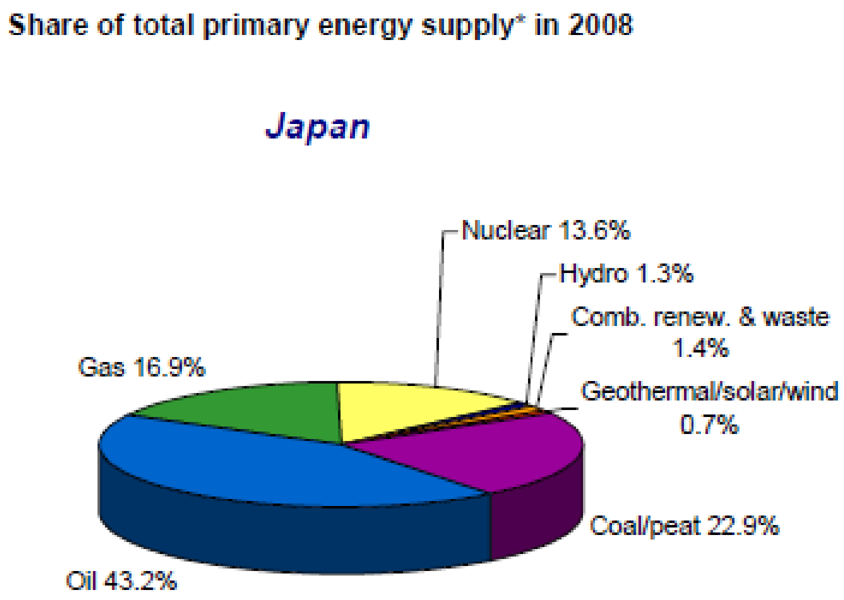
Other energy infrastructure such as electrical grid, refineries, and gas and oil-fired power plants were also affected by the earthquake. Japan likely will require additional natural gas and oil to provide electricity, however power demand may be dampened at least in the short term as a result of the destruction of homes and businesses.

Japan is the third largest consumer of nuclear power in the world, after the United States and France. The internal energy production is widely relying on nuclear, which contribute for a great percentage of electricity generation as well. US Energy Information Administration preliminary data shows that Japan produced 266 GW/h of nuclear-generated electricity in 2009. It is the third-largest nuclear power generator in the world behind the United States and France.

[283] International Energy Agency, Energy Policies of IEA Countries, Japan, cit, p. 147

[284] This is true if hydropower is excluded from the energy mix

FIGURE 43



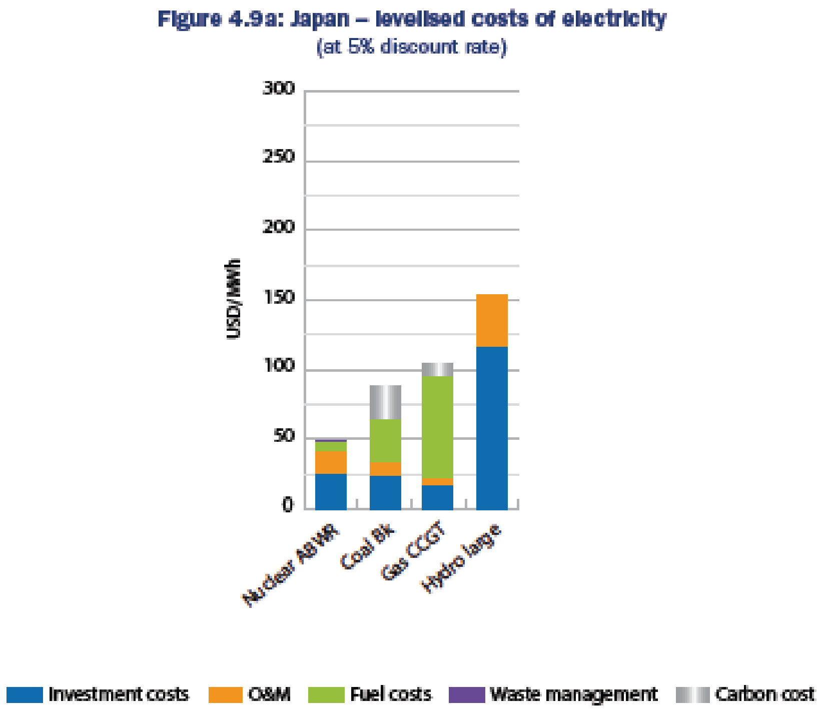
Source: ENERGY POLICIES OF IEA COUNTRIES, JAPAN REVIEW

4.6.2 Nuclear

About the 30% of Japan's total electricity is provided by nuclear energy; drastic decisions on energy policy are expected after the Fukushima accident, but from original plans, the share of atomic energy was supposed to raise in the following decade. LCOE of nuclear is one of the cheapest in Japan and largely cheaper than hydropower[285], using both the 5% and the 10% discount rate.

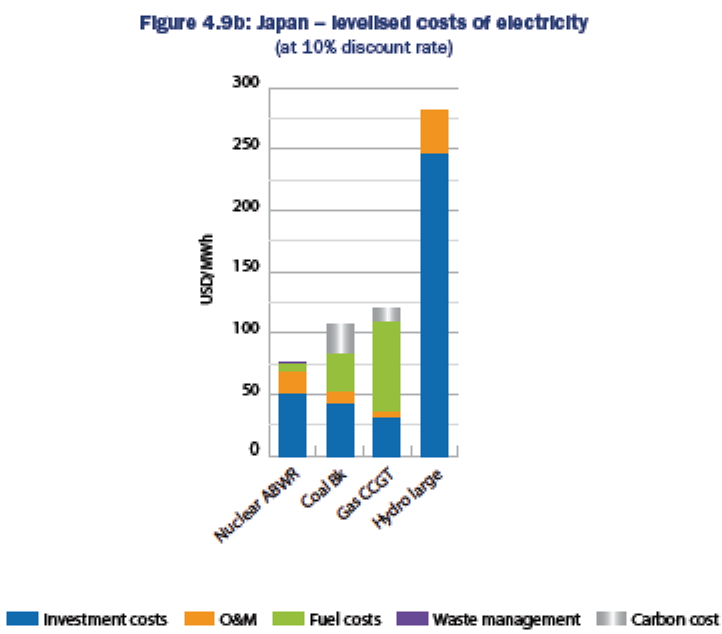
[285] Data on other renewable sources are not provided by the IEA

FIGURE 44



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

FIGURE 45



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

Before the accident, Japan had 55 operating nuclear reactors with a total installed generating capacity of around 49 GWe. Of these reactors, 28 were BWR, 4 were ABWR and 23 were PWR. A further two units are under construction and 11 additional units were in the planning stage[286], now interrupted.

The government stated plans to increase nuclear share of total electricity generation from 24 percent in 2008 to 40 percent by 2017 and to 50 percent by 2030, according to the Ministry of Economy, Trade and Industry[287].

Though, the March 11 earthquake could impact the growth of nuclear energy at least in the short and medium term. Over 12,000 MW of nuclear capacity at the Fukushima, Onagawa, and Tokai facilities ceased operations after the earthquake and tsunami, and some of the reactors could be permanently damaged after emergency seawater pumping efforts[288].

By the way, I could foresee that the country will not phase out the atomic energy, depending strategically on it. There will might be a slowdown in the nuclear expansion due to its low social acceptance.

4.6.3 Hydro and Other Renewable sources

Japan had installed hydroelectric generating capacity of 22 GW in 2008, accounting for about 8 percent of total capacity. The Japanese government has been promoting small hydropower projects to serve local communities through subsidies and by simplifying procedures[289].

There are also a number of large hydropower projects under development, including the 2,350-MW Kannagawa plant due online in 2017 and the 1,200-MW Omarugawa plant due online in 2011[290].

Wind and solar power are being actively pursued in the country and installed capacity from these sources has increased in recent years to about 3.9 GW in 2008,

[286] International Energy Agency, Energy Policies of IEA Countries, Japan, cit, p. 162
[287] US Energy Information Administration, Country Analysis: Japan, 2011
[288] International Energy Agency, Energy Policies of IEA Countries, Japan, cit, p. 162
[289] US Energy Information Administration, Country Analysis: Japan, 2011
[290] International Energy Agency, Energy Policies of IEA Countries, Japan, cit, p. 162

up from 0.8 GW in 2004.

4.7 Russia

Russia is and will remain an energy superpower. It has been a reliable supplier of oil and especially of natural gas over decades through politically turbulent times.

Some political events between Ukraine and Russia in early 2006 and again in early 2009, spilled out into the stability of gas supply in Europe and they did serve to focus the world on the security of Russian gas supply and raised concerns about future Russian gas deliverability[291].

The country is not part of the OECD energy agency, so beyond the so-called International Energy Agency.

Russian enterprises have the engineering and technical skills sufficient for mass production of renewable energy systems. Following the decline in industrial production in the 1990s, many idle plants and factories, especially in the military complex, converted to production of more modern technologies, including renewable energy systems. Today, there are almost 150 Russian enterprises which can manufacture small and large-scale renewable systems[292].

Despite the available technologies and an industrial base sufficient for the mass production of renewable systems, the actual use of renewable energy, except for large hydro, is quite small in Russia.

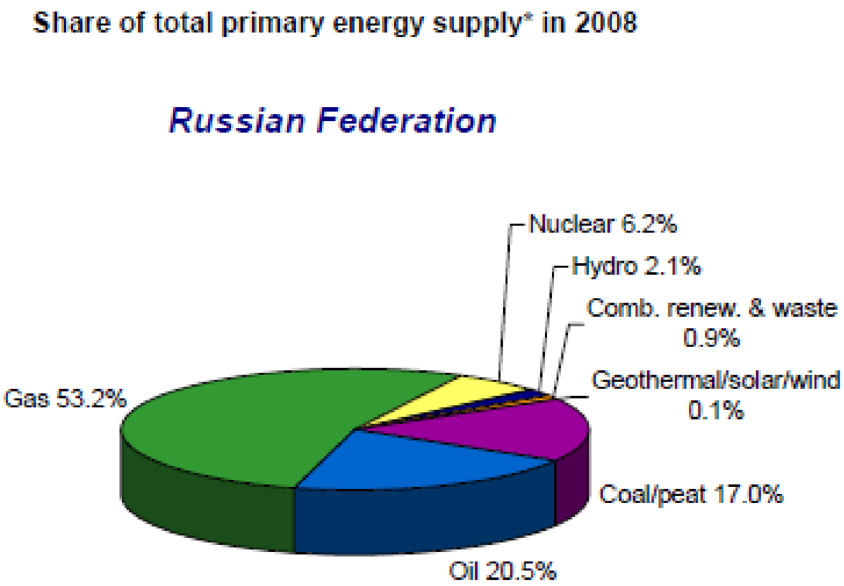
According to IEA statistics, non-hydro renewable energy accounts for slightly over 1% of total primary energy supply.

The LCOE from nuclear is competitive with gas cost production, ranging from USD 43.49/MWh at a 5% dicount rate, and USD 68.15/MWh at a 10% discount rate.

291 IAE website

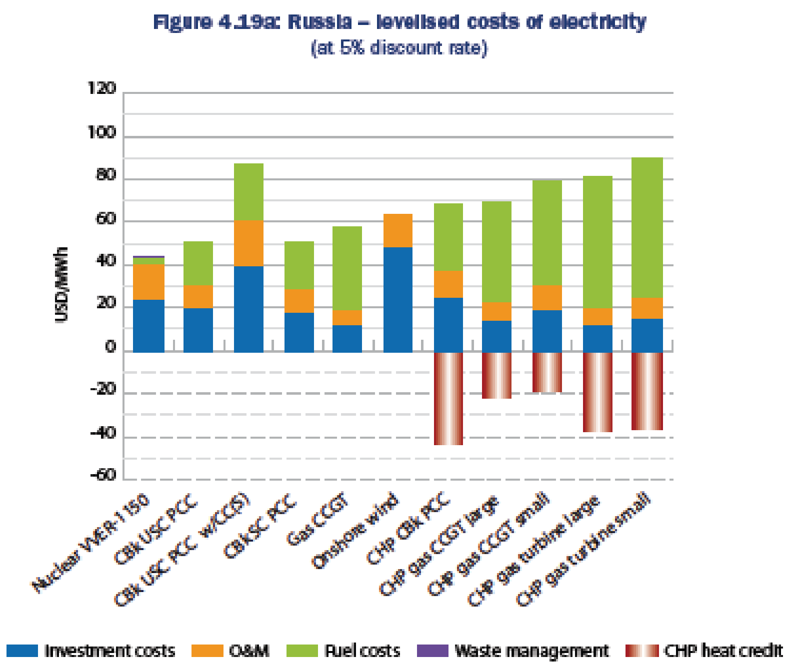
292 International Energy Agency, Renewables in Russia. Paris, 2003

FIGURE 46



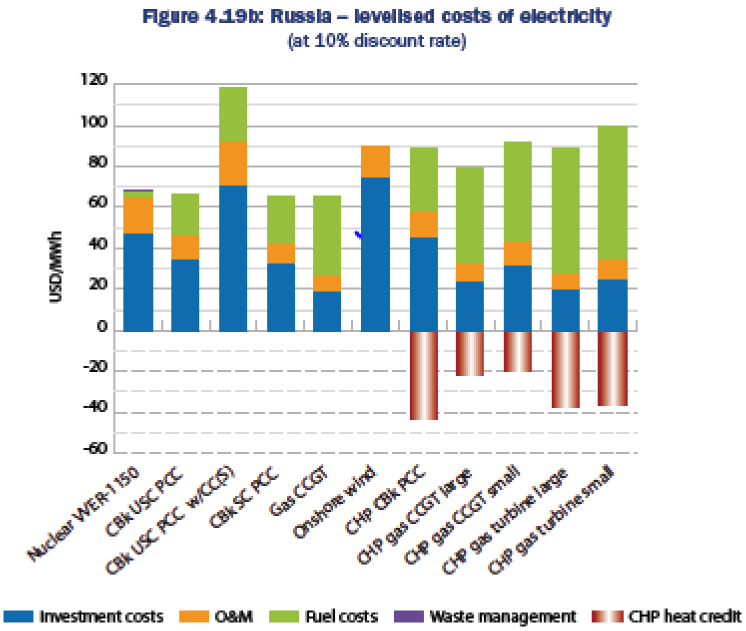
Source: ENERGY POLICIES OF IEA COUNTRIES, RUSSIAN FEDERATION REVIEW

FIGURE 47



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

FIGURE 48



Sources: PROJECTED COSTS OF GENERATING ELECTRICITY

V. ITALIAN SCENARIOS AND PERSPECTIVES. NUCLEAR AND RENEWABLE ENERGIES: ARE THEY ACTUALLY ALTERNATIVE SOURCES?

Italian nuclear energy history has been interesting almost sixty years of our country, from the 40s to the first 90s[293].

After the Chernobyl accident, Italians decided for a complete phase-out of nuclear plants, through a referendum some months after the accident.

The 1987 vote leads to the switched down of the three nuclear plants in operation (Latina, Trino e Caorso) and the immediate interruption of the two in progress (Montalto di Castro)[294]. Italy's phase-out of nuclear energy has led to major costs to the whole economy.

Due to the high reliance on oil and gas, as well as imports, Italy's electricity prices are well above the European Union average. In 2008, the price averaged 20.9 Euro cents/kWh for households, over 9 cents more than in France[295].

Italy has been the only country that phase-out completely its nuclear plants and is currently the only G8 country without its own nuclear power plants, having closed its last reactors in 1990.

In 2008, government policy towards nuclear changed and a substantial new nuclear build program was planned. However, in a June 2011 referendum the 2009 legislation setting up arrangements to generate 25% of the country's electricity from nuclear power by 2030 was rejected[296].

For more than 20 years there has been an intense debate on the return of the atomic energy in the energy mix of the country, which has been experiencing an increase in electricity price, and a relative increase of the dependence of fossil fuels sources.

But a few months before the new vote, the nuclear accident of March 2011 took place in Japan, and negatively influenced the vote on nuclear.

Therefore the country is again out of any nuclear plans for the near future.

[293] A. Sileo, Breve storia nucleare d'Italia, 2008. Available at www.agienergia.it

[294] Enel and EDF, Il nucleare nel mondo e in Europa, Roma, 2010

[295] World Nuclear Association, Nuclear Power in Italy, 2011

[296] World Nuclear Association, Nuclear Power in Italy, 2011

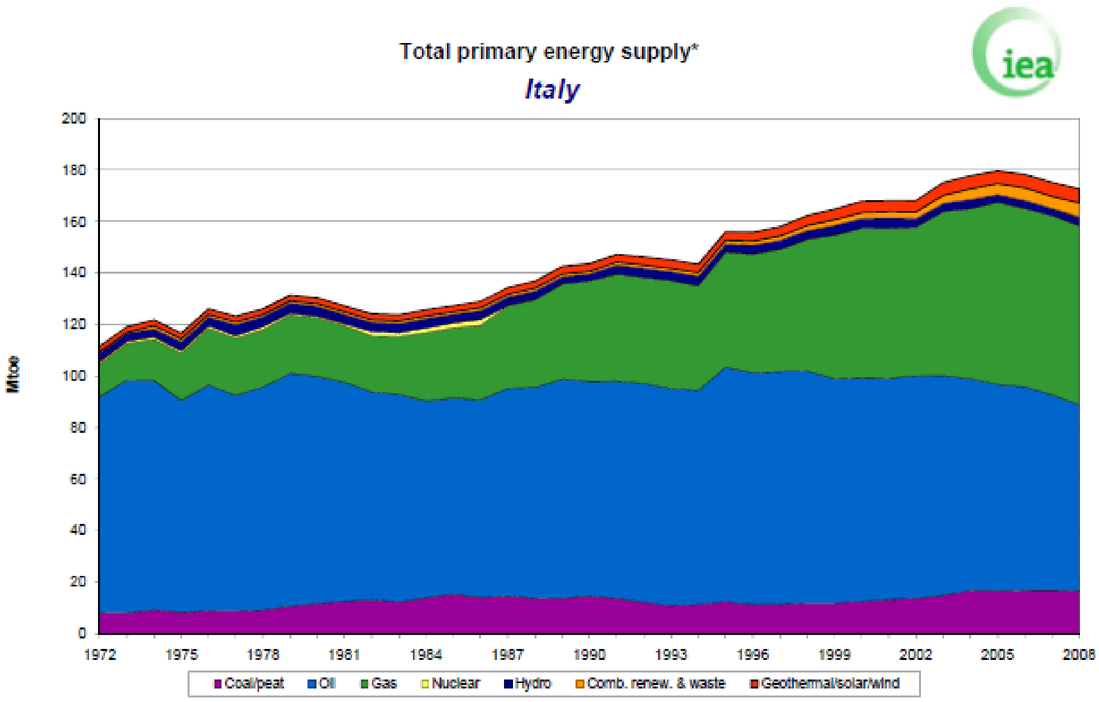
5.1 Current energy framework

Italy's total primary energy supply was 174.5 Mtoe in 2008.

It largely depends on sources not produced in house, gas (40.3%), oil (42%) and coal (9.4%), which lead to a dramatic dependence on suppliers.

The country produces small volumes of natural gas and oil but the majority of fossil fuels are imported[297]. Dependence on imports is widely increasing and accounts for almost 90% of TPES.

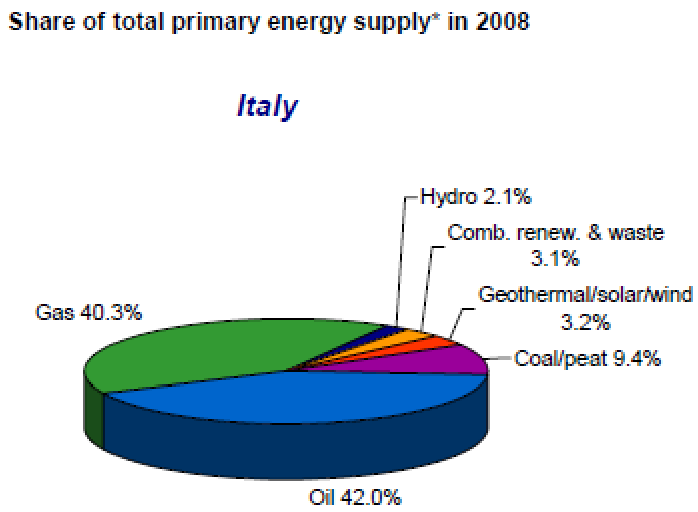
FIGURE 49



Source: ENERGY POLICIES OF IEA COUNTRIES, ITALY REVIEW

[297] International Energy Agency, Energy policies of IEA countries: Italy Review, p. 16, Paris, 2009

FIGURE 50



Source: ENERGY POLICIES OF IEA COUNTRIES, ITALY REVIEW

There is an extreme dependency of the production of electricity on foreign fossil fuel supply, which makes our economy weak in facing the price fluctuation of the gas, and more importantly force us to depend on regions that are politically unstable.

The country must comply with the 2030 UE target of reducing green-house-gas emissions, and reduce its imports dependence as well.

The International Energy Agency provided some suggestions to Italy[298]:

- create a long term strategy for the development of the energy sector, coherent with a liberalized market
- create an efficient process for a nuclear renaissance, investing on structures, systematically following the steps to establish a nuclear program (radioactive waste management, the choice of the location to build nuclear plants etc)
- maintain an independent nuclear safety authority, separate from the R&D activity

[298] Data of 2009

Thus the IEA has invited Italy to rethink the nuclear option, because it could have been a good way to deal with both the environmental concern and the energy dependence issue.

The first energy plan of the current Government foresaw the return to nuclear energy to diversify energy sources, with the construction of 8 to 10 reactors, for a total capacity of 13GW[299]. This would have presumably represented the 25% of the electricity supply of the country.

But this option has been denied by the vote of June 2011.

Concerning electricity production, Italy utilizes mainly oil, gas and coal, practically all imported[300].

In 2009, gross electricity generation in Italy was 290 billion kWh. Of this, 146 billion kWh (50%) was from gas-fired generation; 43 billion kWh (15%) from coal; 28 billion kWh (10%) from oil; and 51.7 billion kWh (18%) hydro. Per capita electricity consumption in 2007 was a little under 5200 kWh[301].

Most of the renewable energy production is represented by hydropower and geothermal. We are using potential of this type already at their maximum.

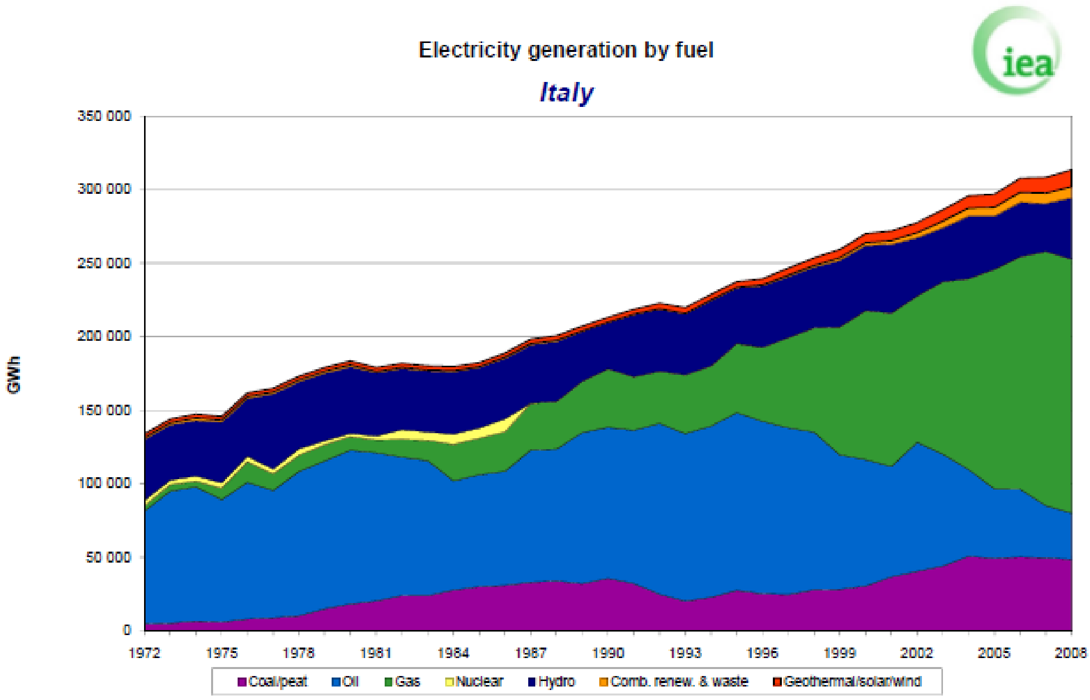
Solar is nowadays increasing over the total amount of electricity produced and can be widely exploited as well as wind power.

[299] Enel and EDF, Il nucleare nel mondo e in Europa, cit., p. 5, 2010

[300] S. Esposto, The possible role of nuclear Energy in Italy, p. 1584, *Energy Policy*, 2008

[301] World Nuclear Association, Nuclear Power in Italy, 2011

FIGURE 51



Source: ENERGY POLICIES OF IEA COUNTRIES, ITALY REVIEW

The levelised cost of electricity of on-shore wind higher than the average G8 and Europe countries, ranging from a 145.50 USD/MWh at a 5% discount rate, to 229.97 USD/MWh, at a 10% discount rate.

This high level is mainly due to a higher investment cost, which include both the overnight cost and the implied interest during the construction.

Germany, France, Canada and the United States, produce electricity from on-shore wind turbine in a more efficient way[302]:

- France: USD 90.20/MWh – USD 121.97/MWh
- Germany: USD 105.81/MWh – USD 142.96/MWh
- USA: USD 48.39/MWh – USD 70.47/MWh
- Canada: USD 99.42/MWh – USD 139.23/MWh

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[302] International Energy Agency and Nuclear Energy Association, *Projected Costs of Generating Electricity*, cit., p. 62

As explained earlier on, solar power is largely the most expensive source, among the so called renewable sources.

This gap is even more dramatic in Italy, where, although the solar industry is experiencing a fast growth, it cannot survive without public incentives.

Its levelised cost of electricity ranges from a low level of USD 410.36/MWh, to a high level of USD 615.98/MWh.

In others country, even though solar is not a cheap source, the LCOE is under our level:

- France: USD 286.62/MWh – USD 388.14/MWh
- Germany: USD 304.59/MWh – USD 439.77/MWh[303]
- USA: USD 215.45/MWh – USD 332.78/MWh
- Canada: USD 227.37/MWh – USD 341.72/MWh[304]

Electricity production from solar power is more expensive in Italy than elsewhere because of a high cost of investment that producers have to face.

This means that the industry must be sustained by subsidies as long as prices fall.

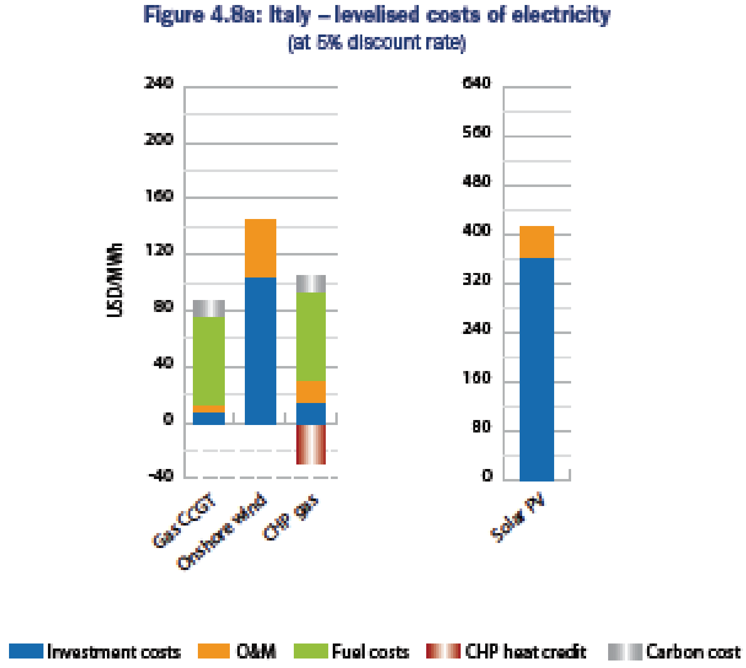
The wind energy industry is much more competitive than the solar one, although we have a greater potential of sun.

These data for Italy are reported in the graphs below:

[303] Data refer to an ‘ open-space’ solar irradiation, which costs less than a roof installation

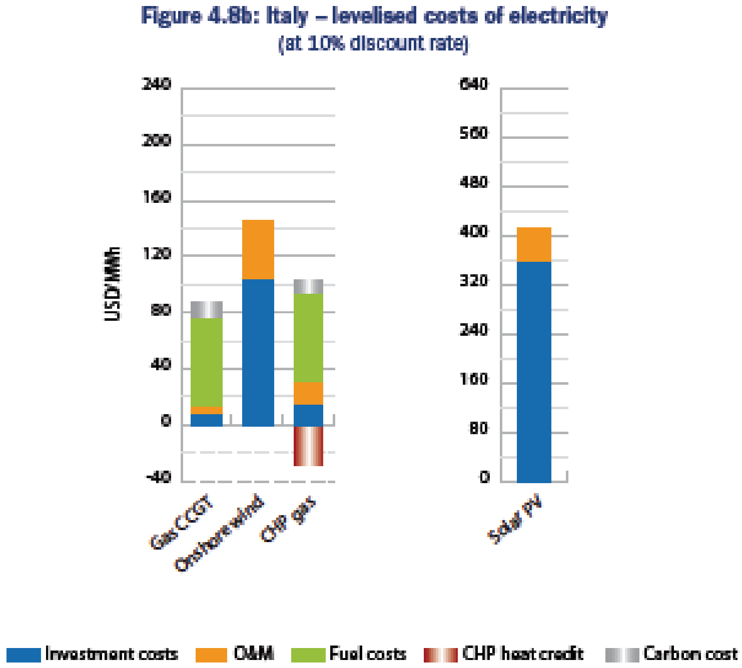
[304] Data refer to industrial installation

FIGURE 52



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

FIGURE 53



Source: PROJECTED COSTS OF GENERATING ELECTRICITY

5.2 Limits to the renewable energies use

Compared with the other European countries, Italy has delayed much the in development and introduction of renewable energy, excluding the ‘‘old’’ hydropower[305].

We are filling the gap both in wind and solar energy sectors.

Our main issue is that we cannot substitute fossil fuels completely with renewable energy sources.

Italy has one of the greatest potential concerning solar irradiation that, although it must be exploited, it cannot cover the all electricity demand.

To give an example of the infrastructure needed, for covering the whole national electricity energy demand, 0.8% of the Italian soil should be covered by photovoltaic systems, a total surface of 2410 km^2.

These values, if the PV cells are orientated at the optimum angle and consequently the maximum efficiency is achieved, and if solution integrated in buildings, evaluation of renewable sources can be affected and increase the area required for the same energy output[306].

There are two different strategies to increase the penetration of intermittent energy source inside a grid, from a 10–20% penetration up to a theoretical 50%, without affecting its stability: load shifting and energy storage[307].

The economic and technical constraints became harder to overcome with the present technology. Moreover, the penetration percentage is linked to the flexibility of the overall electricity production, and the introduction of intermittent renewable energies with shares more than 20% would deeply transform the existing system.

The storage solution is the most interesting but is also the most limited one from a technical point of view. Electricity storage is not considered for large systems due to the limits of battery systems[308].

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[305] S. Esposto, The possible role of nuclear Energy in Italy, cit., p. 1585

[306] S. Esposto, The possible role of nuclear Energy in Italy, cit., p. 1585

[307] P. Denholm, R.M. Margolis Evaluating the limits of solar photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies, *Energy Policy* (2007), 4424

[308] . Esposto, The possible role of nuclear Energy in Italy, cit., p. 1585

A possible scenario mixing wind and PV for increasing the share of electricity produced by renewable energy is possible, and must be considered for the future.
Nonetheless, renewable sources has got fundamental limits to a large scale implementation.
We are far away from a hypothetical framework in which at least 50% of electricity generation comes from renewable sources.
Wind and solar technology, at the current state of technology, has got some main limits:

- limited coincidence between electricity generation and normal demand[309][310]
- high flexibility factor
- prohibitive costs due to an overall immaturity of the sector
- they cannot serve as base load technology

The amount of usable photovoltaic and wind energy is largely determined by the flexibility of the existing electric power system to vary load.
System flexibility is defined as the fraction below annual peak to which a conventional generation fleet may reduce output[311].
Researchers suggest that when the load drop below the 30% of the annual peak, wholesale electricity prices often drop below the actual variable costs of producing electricity[312].
This would imply that generators are willing to sell electricity at a loss in order to keep plants running.

Renewable electricity is the great uncertainty in the future of electricity production. Wind is competitive in some markets. Solar cells are currently too expensive for large-scale production of electricity[313].

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[309] P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, cit.,2855
[310] For solar power, there is considerable coincidence between solar insolation and normal demand in the summer, there is less coincidence during other months
[311] P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, cit.,2856
[312] P. Denholm, R.M. Margolis Evaluating the limits of solar photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies, cit., p. 4425

While only time will ultimately determine if photovoltaic and other renewable electric systems will become highly competitive, there is the real potential that they could become a low-cost source of electricity.

However, their ability to make a major contribution to the world electricity demand depends upon deploying technologies that produce backup power when the sun does not shine and the wind does not blow[314].

5.3 Nuclear option

Italian energy mix is definitely unbalanced toward expensive or polluting sources.

In this chapter I would like to suggest main reasons to rethink properly the nuclear option.

First of all, there is an economic purpose.

G8 and others European countries, have lower electricity price[315], both for the household use and the even more important industrial use.

Two examples are needed:

- a medium firm, which consumes 2 GW/h per year, pays almost two times the electricity price of France, where 76% of the electricity supply comes from nuclear[316]
- the same firm would pay 15% if was operating in Germany, where nuclear is not as relevant as in France (22%)[317].

These are easy example, but they give the idea that, a well diversified energy mix, allows price to go down, and this have a positive impact for the competitiveness of our companies.

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[313] C.W. Forsberg, Sustainability by combining nuclear, fossil and renewable Energy sources, *Progress in nuclear energy*, p.196

[314] C.W. Forsberg, Sustainability by combining nuclear, fossil and renewable Energy sources, *cit*., p. 196

[315] As demonstrated in chapter 3 and 4.

[316] Enel and EDF, Il nucleare nel mondo e in Europa, cit., p. 9, 2010

[317] Enel and EDF, Il nucleare nel mondo e in Europa, cit., p. 9, 2010

On the contrary, paying a higher price for a fundamental input, such as electricity, can boost the production costs, thus in a globalised market, making the company itself non-competitive.

As showed in Chapter 3, the levelised cost of electricity is lower for nuclear than for others base load electricity sources.

Just an exception for large hydro could be made, but would be relevant in Italy, because there is no chance to exploit it more than we have already.

Moreover, nuclear allows price certainty and stability.

Secondly, there is strategic purpose which can be explained by:

- economic diversification of the energy sector
- creation of a new industry.

Following the liberalization of the sector, a proper diversification is needed.

Our mix is dramatically dependent on oil, carbon and gas.

We do need all those technology that can serve as base load electricity generators, including nuclear power, that would be the only one we could produce and control in our boundaries.

Thus a proportional reduction in the other three components, could be replaced internally by nuclear production.

This would lead to the creation of a new industry, with all the benefits coming from it in term of employment, research and development, GDP and so on.

We could also exploit all the knowledge on nuclear issue, that we have widely contributed to create.

Some of the most important research on the atomic energy takes place in our country, and our nuclear engineers are among the best in the world.

Moreover, there is the need to diversify our suppliers.

Nuclear energy can substitute the base load energy production in the Italian system[318].

[318] S. Esposto, The possible role of nuclear Energy in Italy, cit., p. 1586

It is negative, from a geopolitical point of view, to depend on someone else for the supply of energy. It is even worse if our suppliers are political unstable States, which can, in theory, interrupt supplying of fuel. The political instability of the region with the largest oil reservoirs, is a constant threat[319] for prices stability as well.

Italy relies heavily on imports and is the world's largest net importer of electricity.
In 2008, 43.4 billion KWh was imported, and only 3.4 billion KWh exported. Based on total final consumption of 309.3 billion kWh in that year, about 13% of this is accounted for by net imports[320], mostly from French nuclear power stations.
All those cash outflows, could be replaced by internal production and, we could imagine a 100% of self-generating electricity.
But all the alternative source are needed to reach this ambitious target.

This help me to introduce the last reason for re-thinking a nuclear phase out.
The energy industries face two sustainability challenges: the need to avoid climate change and the need to replace traditional crude oil as the basis of our transport system[321].
Radical changes in our energy system will be required to meet these challenges, which may require tight coupling of different energy sources: nuclear, fossil, and renewable.
Nuclear is a zero-emitting source of energy, considered a milestone in the battle against green house gas emissions.
The International Energy Agency has always encouraged governments in investing in both renewable energies and nuclear power.
They can together contribute to the environment battle; a coordinated policy of major Nations is required.

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[319] S. Esposto, The possible role of nuclear Energy in Italy, cit., p. 1586
[320] World Nuclear Association, Nuclear Power in Italy, 2011
[321] C.W. Forsberg, Sustainability by combining nuclear, fossil and renewable Energy sources, cit., p 192

My focus is on the relationship between nuclear, wind and solar energy.

Are they actually alternative sources?

At the current state of technology, they are not.

Wind and solar energies cannot be a base load energy sources, because of the technical limits discussed above.

Moreover, prices are far away from being competitive.

However, in some years, these two renewable sources, wind in particularly, will be performing well, thanks to an increased competition and an improved technology.

Nobody can forecast precisely if and when they will work as base load energy sources.

Nowadays, as long as they are "small and intermittent" energy suppliers, reliance for base load charge, must be on traditional energy sources: gas, oil, carbon.

- they are not own in-house
- our suppliers are political and economical unstable
- they are green house gas emitting and largely pollutant energy.

Nuclear comfortably overcomes environmental concerns, thus being *ceteris paribus*[322], fundamental in a proper mix.

As demonstrated in chapter one, nuclear Generation III+, and in a decade, Generation IV, are safe systems.

they are built to resist to an impact of an aircraft and have passive systems, which can automatically manage human mistakes or natural accidents.

However, in my opinion nuclear energy has still to improve on waste management.

This is currently the issue, that people are more concerned with.

The management of nuclear waste is something than can be achieved in a modern and developed country like Italy[323].

[322] I gave evidence that nuclear is cost competitive with traditional sources.

[323] S. Esposto, The possible role of nuclear Energy in Italy, cit., p. 1586

Although wind and solar power suffers of some limits, due to the early stage of their technology, they have to be exploited, because they will be part of the Italian future, and hopefully of the entire world.
I stressed out their main limits so far, but it is accepted that they have also many advantages:

- contribute to a diversification process
- do not have fuel cost
- fight the environmental problem
- help in creating a new industry

I would dare to propose that nuclear energy, solar and wind power are all needed in Italy. Although the referendum stated the phase-out of nuclear, in some years we will need again a proper debate on the use of the atomic energy.
In the meantime, we have to strongly support wind and solar energy producers:

- incentives to the industry
- research and development
- clusters.

First, individuate specific sites with favourable climate conditions, and create clusters for wind and solar power, is a first possible action.
The phenomenon of firms positioning themselves in a certain area, where there is a specific factor's endowment, has been a common feature in business[324].

Others tools to sustain the development of the sector is represented by the incentives mechanism: subsidies, feed in tariff and tax concessions are some of them.
Of course subsidies have to be reduced as the market increase.

[324] Aarhus area in Denmark, is considered all over the world a perfect example of how a cluster works and generates advantages for the firms which are part of it.

This in my opinion the most important indicator for the growth of solar and wind sectors. If they can survive on their own, a great share of production can be achieved. Otherwise, if operators continue to ask for economic support, it will be a signal of the non-competitiveness of the products.

Lastly, research and development is a fundamental tool to understand if and how these technology can overcome their limits. In ten years, we will know if wind and solar improve so much to be fully competitive as base load electricity generators. Our natural resources, particularly for sunshine, allow to be optimistic, but this could be not enough.

In this likely case, nuclear power in certainly needed, not only in Italy, but everywhere.

Italy should keep on researching on nuclear as well, contributing with the international research, and with the Forum for Generation IV plants.

At the same time, an improve in the social acceptance of nuclear power is needed. After the Japanese accident, the majority of people voted against the nuclear renaissance in Italy, perhaps in a emotional way, not being informed on what nuclear is, how a plant works and what risks really are.

A proper publicity is needed at all levels, and if well informed, public opinion on nuclear energy will positively change.

CONCLUSION

The study conducted took its origins from the necessity of investigating the economic performance of new energy sources.

The world is experiencing some dramatic changes concerning energy supply and demand, and there is a rising concern over environmental issues for the near future.

Thus, changes of energy policy, development of renewable technologies and management of the dependence on fossil fuels, are some of the main points on the agenda of politicians and international Institutions.

The International Energy Agency projections, forecast that the energy sector emissions of greenhouse gases will increase by 130% over the current level by 2050, in the absence of new policies.

Addressing this increase will require an energy technology revolution involving a portfolio of solutions: greater energy efficiency, renewable energy, nuclear power and the de-carbonization of fossil fuel based power generations.

Thus, the idea of focusing on the most debated energy alternatives: nuclear power and renewable energies.

Nuclear has been largely discussed since its first civil usage: argues on the atomic power will probably never end.

After the Japanese accident in Fukushima, there is a general fear of nuclear reactors.

It has been shown that this is partly unjustified, and a proper knowledge of the technology and of its real risks, would increase its social acceptance.

The debate on nuclear power is even of greater interest in our country, Italy, because of the recent popular vote, which has denied any new nuclear programs for the coming years.

Therefore the decision of studying nuclear costs to answer a simple question: “is nuclear power so relevant in modern economies, and if it is, does Italy need it ?”.

Different solutions are found in the work, and different electricity generation costs are studied accurately thanks to a model developed by the International Energy Agency and the Nuclear Energy Association. The research, which have been presented in detail, focuses on the levelised cost of electricity, that is the cost representing the break-even point for electricity generation.

This has allowed economical comparisons of different energies.

The choice of wind and solar power among all the renewable types, has been dictated by the rapid diffusion they are experiencing.

Consequently, there is the need to understand if they are economically sustainable.

Results suggested that nuclear electricity generation is comfortably cheaper than solar power under the assumptions of the model.

Although both the investment costs and the overnight capital costs, are higher for nuclear than for wind and solar energies, the levelised cost of electricity results, show the large economic advantage of nuclear.

Investment costs include all the construction costs as well as the interests paid during the construction.

They vary substantially across countries, ranging from as low as 1556 USD/kWe in Korea as high as 5863 USD/kWe in Switzerland, with a mean value of 4055 USD/kWe.

Concerning on-shore wind power, the data shows a very wide range, with overnight costs ranging from 1821 USD/KWe in France to 3716 USD/KWe Switzerland.

On-shore wind energy outperforms solar' economics everywhere, under any climate conditions.

While its use is small today, solar photovoltaic power has a particularly promising future. Global photovoltaic capacity has been increasing at an average annual growth rate of more than 40% since 2000 and it has significant potential for long-term growth over the next decades.

Results showed that it is much more expensive than wind, with overnight costs exhibiting a range from as low as 3067 USD/KWe in Canada, to 7381 USD/KWe in the Czech Republic.

It is evident from the analysis that the parameter that influences more the gap between nuclear and other renewable types is the load factor. While a constant 80%-85% load factor for nuclear plants can be given for granted, there is not a sure quantity for wind and solar, due to their variable nature.

Storage could be a solution, but the current technology does not allow to store electricity in large amount yet.

The quantity of usable photovoltaic and wind energy is largely determined by the flexibility of the existing electric power system to vary load. Thus, the limited coincidence between electricity generation and normal demand, or worst, peaks, is a main issue for wind and solar.

It would be useful to exploit free natural resources, in the production of the base-load electricity, but this seems to be not easy today.

For their current nature, wind and solar are able to supply a small and uncertain amount of energy.

On the contrary relying on nuclear would mean both facing the base-load demand, and savings in the long term.

It seemed reasonable to forecast a co-existence of the atomic energy with wind and solar power, thus they have been defined “complementary”, rather than alternative sources. This would hopefully be consistent with a competitive energy mix.

Achieving this ambitious target will require a strong and balanced policy effort in the next decade to allow for optimal technology progress, cost reduction and ramp-up of industrial manufacturing.

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