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DEALING WITH EXTERNAL FACTORS IN THE ELECTRICITY GENERATION SECTOR: NUCLEAR VS. OTHER BASELOAD TECHNOLOGIES

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ABSTRACT

The international literature presents several studies about the economics of Power Plants, however these analyses usually consider only the classical accounts related to Construction, Operation & Maintenance, Fuel and Decommissioning cost. Beside these accounts there are many factors, from now on named External Factors (e.g. social acceptability, Security of Fuel supply, etc.) able to heavily determine the profitability and the feasibility of a certain investment. This paper lists the External Factors and, under this prospective, ranks under different scenarios the following technologies suitable for the base-load: hydro, coal, oil, gas and nuclear.

First the paper provides a list of these factors considering the international literature. As second step each factor is analyzed and quantified. Then an overall multi-attribute model, based on the Quality Function Deployment approach, is introduced to obtain a weight for each factor, dividing its impact into three different sustainability dimensions (economic, environmental, social), each weighted according to the investor sensitiveness. Finally the factor weights and their performances are coupled to obtain an overall ranking specific describing the specific environmental coming out by the combination of conditions and investors´ strategies.

The results show that hydroelectric plants are usually the best solution, however there is a shortage of new sites for the further deployment of these plants, therefore other plants have to be considered to fulfill the energy growth. Coal and Nuclear could be a good choice even if each type of plant has its strengths and weaknesses. Nuclear technology has good performances on "fuel supply and environmental impact factors", but his main weak is on the social acceptability. On the opposite the oil and gas -fired plants are always the worst choice. It is important to highlight that some factors are quantified using historical data (for the nuclear sector related to GEN II reactors). This assumption does not bias the analysis since the progress in nuclear energy is present as well as in other technologies. However is clear from the analysis that the innovative passive reactors could overcome other technologies and become the most suitable choice for the base load generation.

1 Scope of the analysis and research questions

Worldwide population growth combined with growing electricity demand requires the construction of more power plants. Most of them are fossil fueled plants (e.g. natural gas, coal and oil). However, (a) the need to contain GHG (Green-House Gas) emissions (as required from Kyoto Protocol), (b) the volatility of fossil fuel price (mainly for oil and gas), and (c) the security of energy supply (due to energy dependence), make nuclear energy a technological option to deal with two important and strongly connected strategic for the next years: energy dependence and global warming.

In the energy and nuclear field most of the researches about the profitability of electrical power plants are focused on the generation cost, using indicators (like the Levelized Unit

Electricity Cost (LUEC)) and the financial performance of the investment (using indicators as the Internal Rate of Return, the Net Present Value, etc.).
Beside these important indicators private or public investor must include in the analysis the so called “external factors”. These factors are called external because they are not under the control of the investor, but they strongly influence the economic performance and the feasibility of the project itself. Examples of external factors are: security of fuel supply, public acceptance, environmental aspect etc.
The main research questions related to the external factors are:

1. How it is possible to rank the different technologies suitable to produce the base load electricity?
2. How they can influence an investor strategy on the electricity generation field?

This paper provides the general methodology as well as the specific algorithms to quantify the factors related to these research questions. The technologies included in the analysis are those usually deployed for the base load:

- Gas-fired plants (Combined cycle)
- Coal (traditional plants without $C0_2$ capture)
- Oil plants
- Nuclear reactors (Light Water Reactor deployed in USA and EU)
- Large Hydroelectric plants

The analysis of the external factors has been developed into two phases:

- The first phase assesses individually the external factors and their differential impact on alternative plant configuration. At the end it provides a “performance scoring” for each factor and each configuration (**pre-requisite**);
- The second phase integrates the factors and ranks the configuration using a multi-attribute evaluation (**integration**).

2 External Factors Model - Methodological approach

2.1 Background and factor quantification

A comprehensive literature about external factors does not exist, but a number of different studies (quoted in the following specific paragraphs) deal with some of them (especially those related to the environmental impact). Therefore the international literature has been used to obtain needed information while for factors without a strong literature background some new indicators have been developed. From this perspective each relative quantification is a new result as well as some of these algorithms used to quantify the absolute values. Also the final integration, performed with well known methodologies provides original results

The evaluation process for each single factor is summarized in these steps:

1. Factor definition;
2. Identification of phenomenon boundaries;
3. Phenomenon observation with the bibliographical analysis;
4. Absolute Factor quantification;
5. Impact on alternatives;
6. Relative impact quantification based on comparison between alternatives;
7. Performance scoring assignment on the basis of the relative impact (Table 1).

Performance Scoring correspondence matrix		
Relative Impact (*RI*)	**Impact Judgment**	**Performance Scoring**
$RI = 0$	*Non existent*	10
$0 < RI \leq 0,4$	*Much Lower*	9
$0,4 < RI \leq 0,8$	*Lower*	7
$0,8 < RI \leq 1,2$	*Appr. Equal*	5
$1,2 < RI \leq 1,6$	*Higher*	3
$RI > 1,6$	*Much Higher*	1

Table 1 Relative Impact

This is the scale that has been used for the comparative evaluation and the performance score assignment for each factor in Chapter 4. It’s important to highlight that this is a “relative” scale where the SMR has a value always equal to 5 and the LR the relative value, so impact judgment are expressed as a relative adjective.

2.2 Multi-attribute evaluation

It is now necessary to integrate the different factors previously quantified to obtain a final summative evaluation of SMR vs. LR. The Quality Function Deployment (QFD [1, 2]), a multi attribute evaluation model, has been chosen as reference to develop an External Factors-impact Integration Model composed by the following two phases: prioritization and selection.

Prioritization

This phase weights the different factors according to a base scenario and three dimensions focused on three different aspects: economics, environmental, social. This phase is composed of the following sub-phases

- each dimension receives a weight d_i according to the investor’s attitude. Four scenarios have been tested: one general (every dimension has the same weight) and three focused on just one dimension: *economy centred environment centred, socially centred*. According to [3] in these cases the focused dimension receives the 80% of the weight (while the others 10% each).
- each link factor-dimension receives a weight proportional to its strength l_i.
- for each scenario an absolute weight is computed for each factor as:

$$F_{ia} = \sum_{i=1}^{3\,(\#\,of\,dimensions)} d_i \times l_i$$

- the weight are normalized among the factors

$$F_{in} = \frac{F_{ia}}{\sum_{i=1}^{6\,(\#\,of\,factors)} F_{ia}}$$

Figure 2 provides a simplified scheme of this model derived from [1].

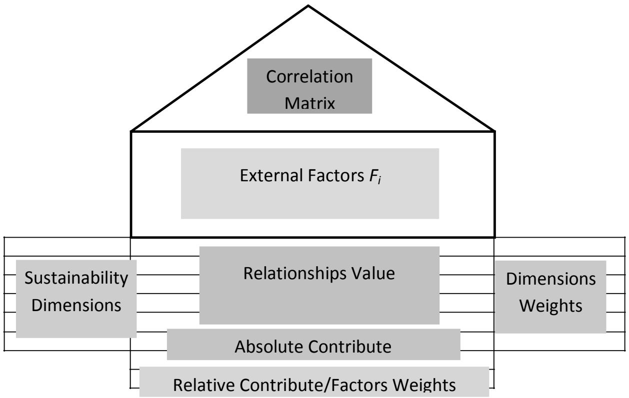

Figure 1 Simplified scheme of prioritization model.

Selection

This phase aims to rank the options by the following two steps:

- multiplying for each scenario the factor's weight F_{in} calculated in the previous phase for the factor's value F_{iv} of each technology to compute the factor score

$$F_{is} = F_{in} \times F_{iv}$$

- summing the previous F_{is} to compute final score for each technology T_s

$$T_s = \sum_{i=1}^{6\,(\#\,of\,factors)} F_{is}$$

Figure 3 provide a simplified scheme of this model [1].

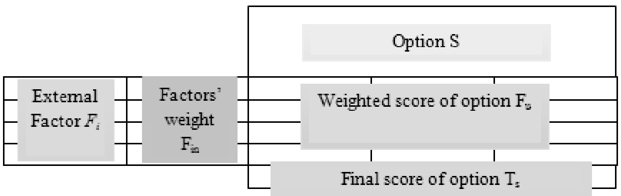

Figure 2 Simplified scheme of integration model.

3 Introduction to the external factor - Nuke vs. other technologies

The literature provides many studies about external factor. However each study focuses on one or few factors (e.g. environmental aspect or volatility of fuel price). There are not works summarizing all these aspect in order to provide a unique evaluation under different scenarios. This section aims to present the most important studies used in the following quantification.

In the last years, the socio-economical landscape of decision makers has shifted from a context mainly characterized by economic factors to another more related to the concept of sustainable development. In this prospective energy and electric sector policy makers have to realize an overall evaluation of different options, covering risks and benefits from an economic, environmental and social point of view.

Several international organizations have developed an evaluation structure for sustainability. The "Three-pillars model" developed by the Organisation for the Economic Co-operation and Development (OECD) [4] is maybe the most important and attempts to describe sustainability through three dimensions: economy, environment and society, with the scope to obtain a final evaluation which integrates these three aspects. The sustainability development structure may be applied to the energy sector with different evaluation purposes.

Different sets of indicators have been proposed from several national and international organizations, and they have obtained validation and approval from both analysts and stakeholders. The most complete are the coordinated effort of United Nations ([5-7]) and OECD project on the sustainability development [8]. Works of the Nuclear Energy Agency ([9,10]) and the International Atomic Energy Agency (IAEA) [11] were focused on nuclear energy suggesting a methodology to assess innovative nuclear technology. Furthermore a study conducted in Germany [12] and Paul Scherrer Institute (PSI) activities in the field of electricity supply technologies [13] covers all the energy system, finding a methodology to assess and compare every single electricity generation. Considering the focus on this analysis the PSI works are a fundamental reference. Also a recent inter-agency effort led by the International Atomic Energy Agency [14] has produced a set of indicators for energy sustainability, coherent with the United Nations Commission on Sustainable Development (UNSCD) structure. Finally, indicators research led by Paul Scherrer Institute (PSI) in the GaBE and New Energy externalities Development for Sustainability (NEEDS) projects context has produced a technology-specific set of indicators. This set is complete but concise enough to be applicable to different case studies, grouping the three aspects of sustainability development (environment, economy and society). From this set of indicators, it has been selected a group of factors coherent with the definition of "external factor".

Considering the cited literature some external factors emerge with a differential impact for nuclear energy respect to other technologies for the production of electricity. All the differential factors summarized in Table 2, have been analyzed in this study, except for the co-generation option and the sitting. Therefore the research covers all the aspects related to an investment in Large base Load Plant without cogeneration. In the fourth paragraph each Factor is analyzed with the specific literature and a synthetic quantification is provided. Values used in the analysis come from the most important bibliographic analysis, therefore, for the nuclear sector, some factor is referred to GEN II reactors and other already deployed plants.

Factor	Type of quantification
Risk of Severe accidents	Monetary
EPZ preparation	Monetary
Security of fuel supply	Monetary
Volatility of fuel price	Monetary
Environmental aspects	Strategic
Public acceptance	Strategic
Co-generation option	Not yet quantified
Sitting constraints	Not yet quantified

Table 2 External factors relevant for nuclear reactor vs. other technologies.

4 External Factors identification e quantification

This section aims to investigate each single factor providing the literature background and the relative quantification.

4.1 Risk of Severe accident

The literature does not provide a unique definition of "severe accident". The ENSAD[a] [15] defines "severe" an accident with at least one of these seven characteristics:

- 5 fatalities,
- 10 injuries,
- 200 evacuees,
- An extensive ban on consumption of food,
- releases of hydrocarbons exceeding 10.000 tons,
- enforce clean-up of land and water over an area of at least 25 km^2,
- economic loss of at least 5 million of USD of 2000.

By using the definition and data from ENSAD, selected aggregated accident indicators have been generated and compared. ENSAD proposes different indicators to compare the "severe accident" among the different technologies. In order to perform the differential analysis we developed the *Specific Monetary Damage per Energy (SMDE),* elaborating the *Monetary Damage per Energy* (MDE) provided by [15]. The MDE can be seen as the "damage cost" in case of severe accident. However since different technologies have different probability of "severe accident" we derived the SMDE. The SMDE quantifies the "risk of severe accident".

The risk of severe accident can be computed as:

Risk of severe accident = Impact of the accident x frequency of accident

Therefore in this case:

Specific Monetary Damage per Energy = MDE [= US$ per Gwe*accident] *x frequency* [= *accidents/year*]

[a] Energy-related Severe Accident Database (ENSAD) created from the Paul Scherrer Institute in 1998 [15].

Table 3 provide the values for the different technologies.

	Tecnology				
	Coal	Oil	Gas	Hydro	Nuke
MDE [million 1996 US$/ (GWe*accident)]	0,0347	0,94	0,11	0,702	1,65
Accident/ Year, derived by [16]	0,0066	0,01034	0,0066	0,0026	0,00032
SMDE = MDE x Accident/ Year [1996 US$/ (GWe*year)]	230	9718	726	1818	532

Table 3 SMDE computation from MDE

The results obtained from the comparison are summarized in Table 4. These results show that coal plant achieves the best performance close followed by the nuclear plants. Oil and Hydroelectric plants are the most exposed to "risk of severe accidents".

Technology	Absolute Impact - SMDE	Relative Impact	Impact Judgement	Score
Coal	230	0,43	*Lower*	7
Oil	9718	18,26	*Much Higher*	1
Gas	726	1,36	*Higher*	3
Hydro	1818	3,42	*Much Higher*	1
Nuke	532	1,00	*Appr. Equal*	5

Table 4 "Severe accident" factor: absolute and relative impact.

It is now important to discuss some peculiar aspects of this quantification.

1. Even if the data refer to GEN II reactor we think that is possible to generalize the relative value (and not the absolute) even to the GEN III and III+ reactors. The latest reactor are much safer than the previous ones (which were already very safe), but also the other plants become more and more safe (at least in the OECD country). Therefore, until new sets of data about the real performance of new generations of power plants will be available, this quantification represents a reasonable proxy.

2. Any fatality has never been recorded for Nuclear Power Plant (NPP) in OECD countries (the Chernobyl accident is happened in Ukraine, a non OECD country), but from a theoretical point of view the fatality rate for NPP exists and comes from the PSA (Probabilistic Safety Assessment). For example this value is between 1.E-5 and 1.E-6 (Fatalities/GWyr) for the European Pressurized reactor [17]. This extremely low value is peculiar of the nuclear technology.

3. Even if the NPP in OECD country never produced a single death, the Three Miles Island accident has been the most expensive accident in the history of power

plant in OECD countries [16]. Moreover the cost associated to an evacuation due, for example, to a terroristic attach can be very relevant even for GEN III reactor. Even if the attack will not cause a severe accident it will be wise to evacuee the population near the reactor. This aspect is similar for hydroelectric plants: they can be considered as target by a terroristic group. On the opposite a coal plant is not a target. Therefore also under this prospective a "risk of severe accident" is intrinsic in the nuclear reactor, even if lower than other types of power plants.

4.2 Emergency Planning Zone preparation

The Emergency Planning Zone (EPZ) is the area surrounding the nuclear plants where preventive/protective actions are planned and implemented in case of accident [18]. As reported in an Environmental Protection Agency (EPA) research [19], *evacuation cost* – the costs associated to the EPZ – is function of three categories of factors:

1. design, construction and operation of the nuclear facility to minimize the likelihood and the consequences of a radiological accident;
2. development of an emergency response plan to enforce the actions to reduce population exposure;
3. expenses necessary to attempt protective actions if case of accident (*response cost*).

Only the last factor is relevant for an external factors point of view because the others are already included in the O&M cost. The total evacuation cost depends on the distribution of population around the reactor and the cost per evacuated person. The last one is determined from different aspects, as evacuation period length and food for evacuees. EPA estimated a cost of 185 $ per person evacuated [19].

The total evacuation cost represents only the 0,49% of the total damage cost of a nuclear accident, but EPZ has an impact also on public acceptance, described in section 4.6. Since the EPZ - evacuation cost is prerogative of nuclear reactor, the impact of this factor can be seen only in nuclear field (Table 5).

Technology	Absolute Impact	Relative Impact	Impact Judgment	Score
Coal	0	0	*Inexistent*	10
Oil	0	0	*Inexistent*	10
Gas	0	0	*Inexistent*	10
Hydro	0	0	*Inexistent*	10
Nuke	0,49	1	-	5

Table 5 "EPZ preparation" factor: absolute and relative impact.

4.3 Security of fuel supply

The literature does not provide a straightforward definition of the concept. However in an a broad sense, security of fuel supply may be defined as the lack of the vulnerability of the system caused by the volatility in volume and price of imported fuel. Economists or other experts [20] proposes a set of indicators useful to measure security of supply used to derive our methodology. In fact from an econometrical prospective an indicator of security of fuel supply should represent a degree of risk associated to:

- dependency of fuel availability with the geopolitical situation of supplier and importer countries
- relative volume of fuel imported.

A possible economic impact of the physical interruption of the fuel can be quantified by using the following model.

Q_E = quantity of energy produced (e.g. KWh)
Q_F = quantity of fuel required to produce Q_E (e.g. Kg)
Q_I = quantity of internal fuel (e.g. Kg)
Q_{IMP} = quantity of imported fuel (e.g. Kg)
p = percentage of fuel imported
$1-p = q$ = percentage of internal fuel
CONV = percentage of conversion of Q_F to obtain Q_E

$$Q_E = Q_F \cdot CONV$$

Where:

$$Q_F = Q_I + Q_{IMP} = pQ_F + qQ_F = pQ_F + (1-p)Q_F$$

So

$$Q_E = [pQ_F + (1-p)Q_F] \cdot CONV$$

If it halves Q_I :

$$Q_I' = \frac{Q_I}{2} = \frac{p}{2} Q_F$$

So it will be obtained:

$$Q_E' = \left[\frac{p}{2} Q_F + (1-p)Q_F\right] \cdot CONV = \left(Q_F - \frac{p}{2} Q_F\right) \cdot CONV = \left(1 - \frac{p}{2}\right) \cdot Q_F \cdot CONV$$

Therefore, the greatest is the p value, the greatest is the half-effect of Q_I on Q_E ($Q_E' < Q_E$).

Q_I reduction has a likelihood called *Risk of Supply* (RS). So the expected[b] quantity of produced energy (Q_E^{ept}) will be:

$$Q_E^{ept} = Q_E \cdot (1 - RS) + Q_E' \cdot RS = Q_E + (Q_E' - Q_E) \cdot RS$$

The lowest is Q_E^{ept}, the lowest is the revenue from the electricity sale. The economic impact is the cost of not satisfied demand (CNSD) is:

$$CNSD = (D - D') \cdot P_p$$

Where *D'* e *D* are respectively Q_E^{ept} and Q_E, that are the quantity of energy with and without risk of supply, and the difference is the not satisfied demand (NSD).

$$NSD = D - D' = Q_E - Q_E^{ept} = (Q_E - Q_E') \cdot RS = \frac{p}{2} \cdot RS \cdot Q_F \cdot CONV$$

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[b] "expected" will be contracted in "ept".

Since the comparison is realized considering the same amount of energy produced, the quantity Q_F•CONV is not differential. Also the percentage *p* is not differential because of its dependency on the energetic policy of the country itself, so it is not an investor's degree of freedom. RS is the only differential variable in this analysis because quantifies the level of centralization of the resources imported.
Referring to the classification of the British Petroleum [21] the globe can be divided into six areas: Middle East, Europe & Eurasia, Africa, South & Central America, North America and Asia Pacific. Therefore the RS is the maximum percentage of fuel imported from a single country/zone (Table 6). Table 7 summarizes the final results using the approach previously described. The Hydroelectric plants are the most vulnerable to the risk supply, but also coal and nuclear are reliable technologies since coal band uranium are spread all over the world. On the opposite the oil plant are very vulnerable from the supply risk since most of the oil reserve are collocated in the Middle East.

Area	Oil (%)	Coal (%)	Natural gas (%)	Uranium (%)
Middle East	**61,0**	0,17	**41,3**	/
Europe & Eurasia	11,6	**32,12**	33,5	**31,0**
Africa	9,5	5,85	8,2	18,0
South & Central America	9,0	1,92	4,4	5,0
North America	5,6	29,56	4,5	14,0
Asia Pacific	3,3	30,38	8,2	25,6

Table 6 Proved reserve for single resources. ([21, 22]**)**

Technology	Absolute Impact (RS%)	Relative Impact	Impact Judgement	Score
Coal	32,12	1	*Appr. Equal*	5
Oil	61,00	2	*Much Higher*	1
Gas	41,30	1,3	*Higher*	3
Hydro	n.d.	n.d.	*Inexistent*	10
Nuke	31,00	1	-	5

Table 7 "Security of fuel supply" factor: absolute and relative impact.

4.4 Volatility of fuel price

Volatility of fuel supply is another aspect of the security of fuel supply. However this factor is function of different aspects connected to the trend of macroeconomic variables.
The fuel cost is a relevant part of the generation cost, therefore a variation in the fuel price becomes a variation in generation cost.
If c_c' is the initial value of the fuel cost and c_c'' is the final value, the variation is given by:

$$\Delta c_c = c_c' - c_c''$$

This value divide by the Energy produced E_p quantifies the specific variation ΔC_{cc} [$/MWh] of the fuel cost

$$\Delta C_{cc} = \frac{\Delta c_c}{E_p}$$

If C_{KWh} is the cost of the energy produced, its variation due to the fuel cost variation is equal to ΔC_c

$$\Delta C_{KWh} = \Delta C_{cc}$$

This value, that can be positive or negative, will be added to the value of the energy produced.
Table 8 reports the values of the percentage impact on the LUEC of doubling the fuel cost according to an IEA and NEA study. Table 9 summarizes the final results. Beside the hydro electrical plant the Nuclear option is absolutely the best choice.

Oil	Coal	Gas	Nuclear	
			U price	***Fuel cycle cost***
26%	40%	75%	4%	15%

Table 8 Impact of a doubling in the fuel cost on the LUEC. [23]

Tech.	Absolute Impact		Relative Impact	Impact Judgment	Score
	At 5% of discounted rate	***At 10% of discounted rate***			
Coal	14,00	17,60	11	*Much Higher*	1
Gas	35,25	38,25	27	*Much Higher*	1
Oil	21,58	23,92	17	*Much Higher*	1
Hydro	0	0	0	*Inexistent*	10
Nuke	1,16	1,66	1	-	5

Table 9 "Volatility of fuel price" factor: absolute and relative impact.

4.5 Environmental aspects

A group of experts [24] has quantified the environmental load of every technology using a standardized LCA (Life Cycle Assessment), by using the concept of externality (or external cost). An externality exists when some negative or positive impact generated by an economic activity are imposed on third parties without being priced by the market [25]. In order to evaluate the externalities the research computes the global emissions of each energy chain. An energy chain or energy system includes all industrial activities directly and indirectly linked with the conversion of an energy carrier (fossil, nuclear) or energy source (solar, wind, hydro) up to the point of its conversion to useful energy (electric, heat, or mechanical).. In order to estimate the related external costs, the emissions are multiplied by the average Unitarian damage factors. The species considered are CO2-equiv, SO2, NOx, PM10, PM2,5, Arsenic, Cadmium, Chromium, Chromium-VI, Chromium-other, Lead, Nickel, Formaldehyde, non-methane volatile organic compounds, Nitrates, Sulfates, primary, Radioactive emissions
Table 10 and Table 11 summarize the results. As expected the Coal technology has the greatest environmental impact, whereas the impact of Hydroelectric and Nuclear plants is

almost negligible. This result is mainly due to the fact that the inevitable air emission of coal and oil plant represents a much greater risk than the correctly managed nuclear waste.

Tech.	External Costs (Euro cent/kWh)		
	min	max	average
Coal	2,80	5,80	4,30
Oil	1,60	4,80	3,20
Gas	1,00	1,60	1,30
Hydro	0,05	0,05	0,05
Nuke	0,15	0,15	0,15

Table 10 Min and max value of external costs. (Elaboration from [24])

Tech.	External Costs (Euro cent / kWh)	Relative Impact	Impact Judgment	Score
Coal	4,30	29	*Much Higher*	1
Oil	3,20	21	*Much Higher*	1
Gas	1,30	9	*Much Higher*	1
Hydro	0,05	0,3	*Much Lower*	9
Nuke	0,15	1	-	5

Table 11 "Environmental aspects" factor: absolute and relative impact.

4.6 Public acceptance

Public acceptance is public attitude towards the deployment of a specific technology [3]. There is not a straightforward quantification of this factor because of its un-deterministic nature. However, there are different impact areas considered as proxies of public acceptance [26].

Table 12 summarizes the social indicators included in the analysis with the relative unit of measurement and the quantification for each technology. The relative Weights have been determined through public and experts polls [17]. Such values have to be standardized to obtain a unique value of the acceptability.

$$Standardized\ value = \frac{V - V_{best}}{V_{worst} - V_{best}} \cdot 100$$

Where V is the value that has to be standardized and V_{best} and V_{worst} are respectively the best and the worst performance in the considered class. Table 13 shows the results obtained.

Impact area	Indicator/ weight (%)	Unit of measurement	Nuke	Hydro	Oil	Coal	Gas
Occupation	Work opportunity for every technology/(10)	man-year/GWh	0,16	1,2	0,47	0,86	0,65
Proliferation	Potential/(5)	Relative scale	100	0	0	0	0
Impact on human health (normal operativity)	Mortality (reduction of life expected)/(40)	YOLL[c]/GWh	0,005	0,011	0,12	0,068	0,023
Local disturbance	Noise, amenity loss/(15)	Relative scale	4	5	6	8	2
Confinement of critical waste	Time of confinement necessary/(15)	Miles of years	1.000	0,01	0,1	50	0,01
Risk aversion	Max num of fatalities per accident/(15)	Max fatalities/accident	50.000	2.000	4.500	500	100

Table 12 Social indicators with relative value and weight. [17]

Impact area	Weight (%)	Nuke	Hydro	Oil	Coal	Gas
Occupation	10	100	0	70	33	53
Proliferation	5	100	0	0	0	0
Imp. on human health (normal practicability)	40	0	5	100	55	16
Local disturbance	15	33	50	67	100	0
Confinement of critic waste	15	100	0	0	5	0
Risk aversion	15	100	4	9	0	0
Total score	100	70	10	58	41	12

Table 13 Assessment of every technology final score.

Assuming that public can observe these indicators (through and adequate communication campaign), the total score in Table 13 represents the absolute value of the "un-acceptability" level for every technology, expressed as social compatibility. Table 14´summarizes the final result: "NON compatibility" parameter represents the level of non acceptability of an option, therefore the highest is the value,

[c] Years Of Lost Life.

the lowest is the public acceptance. Nuclear option has the worst performance because of the risk aversion, the confinement of radioactive waste and the proliferation. Also coal and oil options achieve bad performances because of environmental impact and local disturbance.

Tech.	NOT Compatibility (absolute value)	NOT Compatibility (relative value)	Impact judgement	Score
Coal	41	0,59	*Lower*	7
Oil	58	0,83	*Appr. Equal*	7
Gas	12	0,17	*Much Lower*	9
Hydro	10	0,14	*Much Lower*	9
Nuke	70	1,00	-	5

Table 14 "Public acceptance factor": absolute and relative value.

It is important to highlight that this quantification is based on a correct informative campaign to the public, that allows to transmit the real advantages and disadvantages of each technology.

5 Results

The research provides two basic sets of results.
The first concerns the prioritization of the factors i.e. which are their relative weights. As exposed in the section "2.2-prioritisation" this is related to the scenario considered. This section indicates the most important factors in each scenario.
The second, more important, is related to the technology. As exposed in section four, each factor has a specific quantification for each technology. Therefore, following the guidelines in section "2.2-integration", the integration integrates all the different factors providing a synthetic final result. Since the factors' weights are scenario dependent also the final results will be specific for each scenario.

5.1 Results – factors prioritization

The factors prioritization shows that, independently from the scenario, the risk of industrial accident is always the most critical external factor (Figure 3).
In the Socially centred cases there are two groups of factors: the first is composed by the severe incident followed by environment concerns and public acceptability. This group accounts for the most. On the opposite the importance of the second group (composed by EPZ preparation, Security of fuel supply and volatility of fuel price) is negligible. This strong distinction is absolutely reasonable because the first group of factors has a strong impact on the society. For instance the pollution produced by a certain plant has a strong impact both to the environment and therefore on the social acceptability. Therefore it impacts both on the environmental and social dimension.
The environmental centred case behaves similar to the social case, but with an important difference: the importance of the public acceptance is negligible respect to the risk of severe accident and environmental aspect. This is reasonable since the public acceptance includes irrational fears, while the environmental aspects reflect the real externalities of a certain power plant.
On the other hand the pollution is typically an "externality" (as defined in section 4.5), therefore the cost is not paid by the investors. This is reflected in the economy centred case where other factors account more. In this case the severe accident is still the most important because the costs coming from an important accident are so high that could even cause the bankrupt of the utility. EPZ preparation, security of fuel supply and environmental aspects are the other factors with a high weight: these aspects can deeply affect the profitability of an investment. On the other hand Environmental aspect and public acceptance have a lighter weight, however not negligible. These aspects are becoming day by day more important: the emission trading would shift some cost from external to internal and the public acceptance can lead to expensive delay in the implementation or even to the cancellation of a project. The Base case summaries these aspects, balancing the different factors. As expected the risk of severe accidents is the most important.

5.2 Results – integration

It has been found in chapter 4 that, for each factor, the hydroelectric plant is always the best choice or at least receives the same scores of the other technologies.
Figure 4 reflects this aspect: the hydroelectric plant is always the best choice in each scenario. This is reasonable since this technology produces a negligible amount of pollution, so it is not affected by fuel's cost concerns and it is typically well accepted.
However there is a shortage of new locations suitable for the construction of large hydroelectric plants (at least in Europe), therefore other plants are absolutely necessary.
Figure 5 focuses on the other technologies. In all the scenarios Oil-fired plants are the worst choice: these plants suffer for the fuel concerns (the volatility and the Security of fuel supply) as well as the high environmental impact. Considering the external cost the deployment of this type of plants should be avoided. Also the Gas plants do not receive an high score. This is due to the risk of severe accidents and to the high impact of a cost increment in the gas supply.
Coal and Nuclear are the best technologies in all the case getting a similar result. However considering the scenario focused on the environment the nuclear option is the best choice because of its low externalities and a remote risk of severe accident.

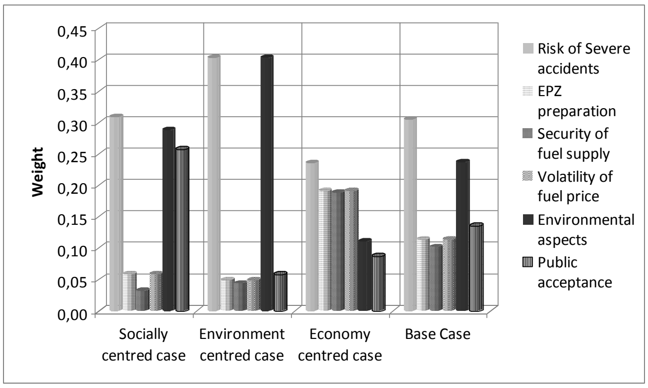

Figure 3 Nuclear vs. other technologies. Factors weights according to the different scenarios

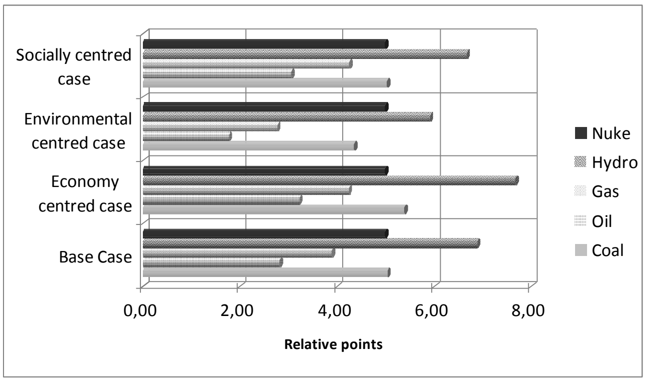

Figure 4 Nuclear vs. other technologies. Results in the different scenarios

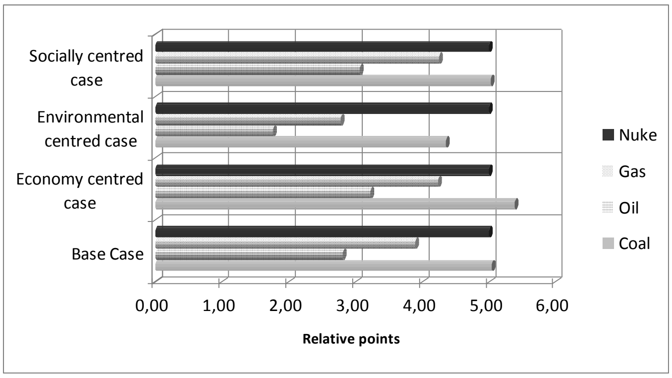

Figure 5 Nuclear vs. other technologies without Hydroelectric plants. Results in the different scenarios.

6 Conclusions and further developments

This paper represents a first quantification of the external factors, i.e. factors out of the control of the investor and of the user itself. The results show that, considering the traditional generation technologies, nuclear plants is usually the best option with coal, even if this technology suffers for the social acceptability in many countries. This result is consistent with the UE, and USA history where for 20 years any new plants has been built and some countries (Italy, Sweden, Germany) decided for a phase out policy.

However this result is not due to the technology itself, but mainly to the adverse and sometimes irrational and public opinion. Correct information, as in France, can deal with this problem changing the final results. The main massages of this analysis is that the nuclear option is very attractive (even beside the low cost of the kWh), because of the extremely low environmental impact and the low impact of risk in fuel supply.

Under this prospective seems clear as the nuclear technology provides advantage for both investors and common citizen: the first gains advantages from constant cash flow coming from an almost fixed generation cost (mainly due to the Capital cost) and the second gain advantages from the low environmental impact as well as the low cost of electricity.

Moreover is fundamental to consider that this analysis includes the performances of old GEN II reactors, therefore we expect that the new reactors will perform much better. Preliminary results of a comparison among innovative passive SMR vs. LR confirm this intuition [28].

In this research area there are three main streams for further developments.

The first is related to the factors quantification and should include a quantification of: generation options and sitting constraints as well as a better quantification of the public acceptability. We aims to understand which are the main factors related to this later aspect and how is possible to increase the social acceptability for the new nuclear power plants.

The second stream is related to the factors prioritization, since the expert elicitation is necessary to work out more accurate weights for the different scenarios.

The third stream aims to perform an analysis using innovative power plants, such as Integrated Gasification Combined Cycle (IGCC), and GEN III+ reactors. However the literature does not provide yet a complete set of data about the real performance of these plants.

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