A FRAMEWORK FOR THE SELECTION OF THE RIGHT NUCLEAR POWER PLANT

ABSTRACT

Civil nuclear reactors are used for the production of electrical energy. In the nuclear industry the vendors propose several designs of nuclear reactors with a size from 35-45 MWe up to 1600-1700 MWe. The choice of the right design is a multidimensional problem since a utility has to include not only financial factors as Levelized Cost Of Electricity (LCOE), Internal Rate of Return (IRR), but also the so called "external factors" like the required spinning reserve or the impact on the local industry or the social acceptability. Therefore it is necessary to balance advantages and disadvantages of each design during the entire life cycle of the plant, usually 40-60 years.

In the scientific literature there are several techniques to solve this multidimensional problem: unfortunately it seems not possible to apply these methodologies as they are, since the problem is too complex and it is difficult to provide consistent and trustworthy expert judgments. This paper fills this gap proposing a two-step framework to choose the best nuclear reactor at pre-feasibility study phase. The paper shows, in detail how to use the methodology comparing the choice of a Small Medium Reactor (SMR) with a Large Reactor (LR), characterized, according to (IAEA, 2006), by an electrical output respectively lower and higher than 700 MWe

Keywords: Not monetary factors, life cycle evaluation, AHP, multi attribute evaluation, nuclear power, SMR.

1. INTRODUCTION

One of the most important elements in the production of electricity is the choice of the most appropriate power plants. This selection takes place in the pre-feasibility study, and it has to include financial and numerical values (e.g. Net Present Value - NPV, Capital Employed) as well as other non-financial aspects (e.g. safety), both intrinsically uncertain. The non-financial aspects become definitely relevant when the consequences of the selection impact on many stakeholders. For instance, choosing plant "A" instead of plant "B" can promote the development of national industries, increase job positions, or reduce some risks. So, even if some of the financial performances of plant "B" are slightly better than plant "A", it may be wise to choose plant "A". The same considerations apply when the issue is "Producing electrical power by developing new Nuclear Power Plants (NPPs)": different projects have to be evaluated in order to find the most adequate size and design.

In order to assess strengths and weaknesses of Small-Medium Reactors (SMRs) an INtegrated model for the Competitiveness Assessment of SMRs (INCAS) has been developed. INCAS compares the choice of investment in SMRs or LRs providing monetary and non-monetary indicators. Carelli et al. (2009) and Boarin and Ricotti (2009) presented economic and financial comparisons of Large and Small-Medium designs. Locatelli and Mancini (2011) show how to deal with non-monetary factors.

The goal of this paper is to define a framework to integrate both contributions of different nature, which is mainly the area of applicability of Multi Criteria Decision Making (MCDM) methods. Literature proposes many tools for the decision maker; however, it is not clear which is the best procedure to be used to select the right NPP design considering different factors that can be quantitative (monetary and non-monetary) or qualitative/strategic. This paper fills the gap in the literature proposing a two-step framework that has been implemented in a case study: the selection of the best NPP technology.

2. EXTERNAL FACTORS

The necessity to consider aspects of different nature has been grown through years, especially in the evaluation of policies and technologies for electricity generation (Haralambopoulos and Polatidis, 2003, Pohekar and Ramachandran, 2004). For example Mirasgedis and Diakoulaki, (1997) consider, during the operations phases, the costs of environmental impact and externalities to determine energy price. They try to translate the physical impacts of different technologies into monetary terms: for traded goods impact evaluation is based on the average prices in worldwide market, for non-traded goods estimates are based on surveys about the common Willingness To Pay (WTP) to avoid the impact of externalities. The translation of physical externalities into monetary terms is often complicated and could be a wrong solution when considering aspects of different nature:

- WTP approach is too subjective and could drive to less robust rankings of alternatives;

- Some factors affecting investment rating are characterized by a qualitative nature whose monetary translation would be meaningless, too complicated or too subjective. As Saaty (2008) states: "*To make a decision we need to know the problem, the need and purpose of the decision, their sub-criteria, stakeholders and groups affected and the alternative actions to take [...] but there are many more important factors that we do not know how to measure than there are ones that we have measurements for*".

These factors, which are less controllable by investors and heavily influence the operations, will be named as external factors. We define as external a factor we cannot consider in traditional Discounted Cash Flow methods (DCF methods) methods for the evaluation of investments, because of its qualitative and subjective nature, but which is able to heavily affect the investment attractiveness. Adler (2000) highlights the importance of such factors. He states that traditional approaches for projects' strategic evaluation, based only on monetary indicators such as IRR or NPV, suffer from too narrow perspective and inability of considering potential non-financial benefits, which often characterize strategic investments.

Locatelli and Mancini (2011) list and explain external factors which are differential for the choice between LRs and SMRs. According to this work, three groups of external factors have to be considered in the selection of the right NPP technology:

- *Site-related factors*, which influence the number and the extension of available locations for new NPPs: Technical Siting Constraints, Local Population's Attitude, Spinning Reserve Management and Electric Grid Vulnerability;

- *Welfare-related factors*, which impact on country's population well-being: Impact on employment, Impact on National Industrial System, Levelized Cost Of Electricity and Time-to-market;

- *Project-Life-Cycle-related factors*, which impact on project's robustness looking at its whole life cycle: Historical and Political aspects, Incremental Design Robustness (Safety), Risks and Competences required for the operations.

SMRs were developed during the '50s and the '60s: then, in order to exploit the "economy of scale" the design was scaled to 1 GWe and more. But innovative SMRs exploit their small/medium size to develop features giving them benefits in economics, as well as in safety and operational flexibility: it is already been proved that, in a certain scenario, the loss of "economy of scale" can be balanced by the "economies of multiples" such as standardization, learning, cost sharing, modularization etc. (Ingersoll, 2009).

Thanks to the reduction of financial gap and thanks to SMRs' flexibility and adaptability, the right choice between LR and SMR increasingly requires the integration of financial and external factors.

3. LITERATURE REVIEW

The integration of financial/monetary factors and external factors performances requires the application of MCDM techniques, which were developed to choose the best alternative based on different nature criteria.

There are two clusters of MCDM methods (Ribeiro, 1996):

- *Multi Objective Decision Making (MODM)* methods, which support decision making processes on continuous spaces. MODM consists of a set of conflicting goals which cannot be achieved simultaneously and which can be solved with mathematical programming techniques (Ribeiro, 1996). Major MODM methods are optimization techniques, which try to represent problems through continuous functions (Figueira et al. 2005). MODM cluster contains Multi Attribute Utility Theory (MAUT) methods, in which each attribute evaluation is expressed by a common scale (Dyer, 1979), which is independent from the specific unit of measurement;

- *Multi Attribute Decision Making (MADM)* methods, which deal with the problem of choosing the best solution among a finite set of alternatives. They provide for the application of discrete mathematic to a finite and preconceived group of alternatives (Ribeiro, 1996).

The rigorous mathematical programming of MODM methods is not appropriate to solve the problem of the right NPP design selection, which requires evaluating a finite number of alternatives. MADM methods fit well this need but their cluster is very wide. So, a critical literature review of MADM methods was performed: Table 1 summarizes the most common and powerful techniques, their strengths and weaknesses and the references considered.

PLACE TABLE 1 HERE

Saaty's Analytic Hierarchy Process (AHP) is one of the most used methods, because of its ability to fit different problems. It could be also implemented through a fuzzy approach, which permits to elicit expert opinion using linguistic variables. Fuzzy AHP better follows the human thinking

(Deng, 1999) because not every pairwise comparison can be expressed by a precise ratio number; a fuzzy set which takes uncertainties into account fits better (Hsieh et al. 2004). The main problem of fuzzy version is the complex and unreliable process of ranking fuzzy sets resulting from evaluation of alternatives (Leung and Cao, 2000).

Outranking methods are usually employed in the ranking of many alternatives but some of them, like ELECTRE or PROMETHEE, have the advantage of being based on a global preference model, expressed by preference and indifference thresholds, which permit to express different degrees of preference between two alternatives. The main weakness is the high number of threshold values required by the decision maker.

TOPSIS is intuitively appealing and easy to understand (Opricovic and Tzeng, 2004): it is based on the assumption that the best alternative should have the shortest Euclidean distance from an ideal positive solution (made up of the best value for each attribute regardless of alternative) and the farthest distance from a negative ideal solution (made up of the worst values). Differently than outranking methods, further thresholds or parameters are not required. Each performance can be considered in the model through its specific measurement.

4. THE TWO-STEP PROCESS

The choice of the right MADM technique requires a deep analysis of strengths and weaknesses of each method: some have a solid and reliable mathematic basis; others can be implemented in a simpler way (Kiker et al. 2005).

In the scientific literature, few comparative evaluations among MADM methods can be considered independent from the specific case study and this demonstrates the inexistence of a single preferable method. Such comparative evaluations cross many different sectors. In environmental policy decision making, Greening and Bernow (2004) state that a MADM technique must be able to consider every stakeholder's opinion, but the right method is definitely case-specific. In other comparative studies (Zanakis et al. 1998, Karni et al. 1990) the objective is usually the evaluation of consistence in rankings obtained from different MADM methods. Finally no study states the supremacy of a specific method, but each demonstrates that every MADM process requires two kinds of information:

1. The performances of different alternatives on each attribute considered in the decision making process;

2. The relative importance of different attributes with regard to the objective of the decision making: importance must be represented through importance weights.

In the selection process different designs are evaluated on financial and external attributes: financial and external performances and weights are then combined through MADM techniques for the final prioritization.

So, it is useful to separate MADM methods in two different groups:

1. Methods requiring importance weights as inputs from external sources: they are Scoring Methods, TOPSIS, ELECTRE and PROMETHEE. These require the combined usage of other techniques providing the weights;

2. Methods which calculate importance weights as part of their integration process: AHP and its fuzzy version.

Therefore AHP and fuzzy AHP could be implemented in two different ways:

- To support the whole process, till final prioritization (Al-Harbi 2001, Yang and Chen, 2004);

- To determine only importance weights (Kuo et al. 2002, Kwong and Bai 2002).

Finally, the choice is between a *one-step* and a *two-step* MADM process. In a *one-step process*, AHP or fuzzy AHP use expert elicitation based on pairwise comparisons to get prioritization and final ranking of the projects (Saaty 1980, 1990, 2008). In a *two-step process,* AHP or fuzzy AHP can be used to get importance weights through expert, stakeholders and decision makers elicitation; then weights will be integrated with financial and external performances of NPP designs, using Scoring Methods, TOPSIS, ELECTRE or PROMETHEE.

The main implications of this choice are:

- the one-step process is based only on expert elicitations and it is not able to include numerical ballpark estimates of financial indicators usually available in a pre-feasibility study (which are essential information for the choice that can be wasted);

- attributes' weights are *case-specific* and, especially in the pre-feasibility phase, the best way to get them is the elicitation of expert and decision maker opinions. Pairwise comparisons of AHP or fuzzy AHP are the simplest and most efficient way to elicit expertise (Hamalainen 1990, Hsieh et al. 2004).

Previous considerations show as the two-step MADM process can be the baseline choice for the selection of an industrial plant. It permits to include expert elicitations for weights and, on the other hand, to consider financial and external factor using a non-AHP method for the final integration.

Now it is necessary to choose the right MADM method for each phase.

AHP and fuzzy AHP are the best methods to obtain the weights (Table 1 and Table 2). Scoring methods, ELECTRE, PROMETHEE and TOPSIS are available for the final integration (second phase). Table 2 summarizes strengths and weaknesses of methods considering the specific

requirements of each phase and of the specific decision making process "*Selection of the best NPP design for a certain country*".

PLACE TABLE 2 HERE

According to the critical review (Table 2), we suggest the choice of fuzzy AHP and TOPSIS methods. Fuzzy version of AHP takes into consideration the uncertainty on judgments from experts and, above all, it eliminates the need to express judgments of relative importance in form of crisp numerical value, as for traditional AHP. Fuzzy AHP is perfect to get weights from expert elicitations, as demonstrated by numerous similar applications in literature (Kahraman et al. 2004, Kahraman and Cebi 2009, Hsieh et al. 2004, Chiou et al. 2005, Beccali et al. 1998). TOPSIS will be exploited for the final integration because it is really simple and easy to understand: these are the most important characteristics for a tool supporting selection and pre-feasibility phases.

Many parameters required by other methods would make the second step too complicated, without ensuring a more accurate evaluation because in the selection phase decision makers are still dealing with ballpark estimates. Figure 1 provides an overview of the rationale to select Fuzzy AHP and TOPSIS

PLACE FIGURE 1 HERE

Finally, the complete process for selection of the best NPP design for a certain scenario can be summarized in 6 points:

1. Identification of relevant attributes for evaluation and selection. These depend on market, products, technologies etc.

2. Definition of measurement and evaluation process of each attribute: quantitative or qualitative, monetary or not, etc… Each choice has to be evaluated respect to each attribute.

3. Definition of attribute's hierarchical structure as required for fuzzy AHP application.

4. Expert elicitations to obtain the attributes' weights. Each expert has to fill in a questionnaire of pairwise comparisons between attributes or groups of them. Fuzzy AHP permits to express judgments through linguistic variables: each one is linked to a triangular fuzzy number following the scale in Yang and Chen (2004).

5. Aggregation of the Pairwise comparison matrices from different decision makers using the geometric mean method presented in Kuo et al. (2002). The Buckley's method presented in (Buckley 1985, Kahraman and Cebi 2009, Chiou et al. 2005) is then baseline choice to obtain the final importance weights. These are fuzzy sets, so a defuzzification process like in Kahraman and Cebi (2009) is needed to obtain crisp values. The most common is the Centroid Method presented by Opricovic and Tzeng (2004) and other authors (Chiou et al. 2005, Kuo et al. 2002, Hsieh et al. 2004).

6. **TOPSIS** is applied for the final integration as presented by Hwang and Yoon (1981) and Opricovic and Tzeng (2004).

The intuition of using Fuzzy AHP and TOPSIS for project selection is supported by Mahmoodzadeh et al. (2007). Starting from Mahmoodzadeh et al. (2007) this paper proposes a dramatic development since:

- Mahmoodzadeh et al. (2007) deal only with four financial factors, while this paper shows how to include financial/monetary factors (six, including their variance), not financial quantitative factors (six factors), not financial qualitative factors (six factors).

- Mahmoodzadeh et al. (2007) have a single cluster of factors while this paper shows how to cluster factors into four groups and how to deal with more than one groups (see Figure 2)

- This paper provides an extensive bibliographic review explaining why, for this class of problems, the Fuzzy AHP and TOPIS are the best approach. Mahmoodzadeh et al. (2007) deal with the mathematical side providing the full set of equations (that are not an original contribution). They do not compare these methods with other methods (like ELECTRE and PROMETHEE) and do not justify their choice for the selection.

5. SELECTING THE BEST NUCLEAR POWER PLANT TECHNOLOGY FOR NEWCOMERS IN THE NUCLEAR MARKET

The six-step method presented in the previous section is now implemented to deal with the evaluation of LRs and SMRs respect to a given scenario. The scenario refers to a country that can be considered new-comer in the nuclear market, (e.g. Chile, Bangladesh and Egypt) or without a strong national manufacturing nuclear industry (e.g. Spain, Argentina and Finland). The power to be installed is about 10-15 GWe. As said in section one, this case study is included in the application of the whole INCAS model.

Points 1-2. The first two points are carried out in the development of INCAS: decision makers, experts and literature review indicated 18 relevant attributes evaluating NPP project attractiveness. As presented in Figure 2, six are from traditional DCF methods, other are qualitative and quantitative external factors, already listed in section two:

* Among the financial factors, IRR, its variance and Payback Time have been chosen to consider expected profitability and risk of LR and SMR investment. Equity Employed and Max Cash Outflow evaluate the expected impact of self-financing: sequencing NPP unit construction in the right way, investors can capitalize power production from the first installed units, reducing need for debt or equity. This is the so called "self-financing option";

* Locatelli and Mancini (2011) developed a specific model to evaluate LRs and SMRs the performance of each Non-DCF attribute (Site, Welfare and Project Life Cycle related).

PLACE FIGURE 2 HERE

The default scenario is composed of 13 GWe, considering 6 sites available for the installation. The LR scenario is composed of a mix of four 1600MWe and six 1100 MWe Power plants, while in the SMR scenario there are 39 335MWe power plants. INCAS evaluated the overall performances respect to each attribute.

The goal of the INCAS analysis was to investigate the attractiveness of an investment in new "Deliberately" SMRs by means of a systematic and comprehensive approach. SMRs are a "new product" in the nuclear industry since they are not a scaled version of LR, but a new concept of NPP. They aim to take advantage of a smaller size to implement new technical solutions and an easier construction. SMRs intend to exploit the "economy of multiples[1]" rather than the "economy of scale". The IRR is one of the most important financial indicators for the investors, in particular when utilities are privately held companies aimed to maximize the return for the investors. According to Boarin and Ricotti (2009) LRs are more profitable because of a higher IRR. The SMRs are attractive in scenarios with limited financial resources, where the utilities can add modules exploiting the self-financing options: the maximum financial exposition can be reduced so even if the capital cost is slightly higher for the SMRs thanks to the self-financing option, the capital employed (Debt + Equity) is similar. This is due to the compensation of the "economy of scale" with the "economy of multiples". Therefore instead of a monolith LR providing at once a large amount of power, a series of SMRs allows a gradual connection to the electricity grid. With this approach the first units can finance the construction of the following units, reducing and diluting the upfront investment. With this approach the shareholders receive a lower remuneration of their equity since the inbound cash flows are gathered later. SMRs, due to the lower up-front investment, can be a reasonable choice in case of limited resources since they can "wait and see" multiple strategies. The contemporaneous construction of a large number of SMRs is not a reasonable choice because they cannot reap the advantages from learning and self-financing i.e. the "economy of multiples".

According to Locatelli and Mancini (2011) SMRs perform better, or at least as well as, LR in all the external factors except historical and political aspects. However it is important to point out

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[1] Economies of multiples refer to the economic advantages in deploying many identical units. If 100$ is the cost of a single unit the deployment for n identical units is less than 100 $ x n because of the cost savings from: industrial learning, standardization and mass production, cost sharing of non-recursive costs (e.g. in the Engineering, in the design), sharing of site fixed and semi-fixed costs etc…

that the Not In My Back-Yard (NIMBY) syndrome limits the possibility of spreading SMRs in different sites, and so to fully exploit the advantages in grid stability and site availability. However even if many SMRs are grouped in the same site they still have many advantages through all their life cycle. During the planning and construction phases, more sites can be exploited, the time to market is shorter and there are fewer risks associated to the construction. In the operation phase, SMRs provide more job positions and require smaller spinning reserves.

Point 3. The hierarchical structure for the implementation of fuzzy AHP is presented in Figure 2. To cluster the factors into groups have two main advantages:

1. Reduce the number of pairwise comparison

2. Allow an easier judgment since the factors in the same group are comparable

Point 4. Elicitation is obtained through a questionnaire designed for fuzzy AHP, following the scheme presented by Ozdagoglu and Ozdagoglu (2007). The questionnaire contains 34 questions: each one is related to a pairwise comparison, resulting from the previous hierarchical structure, and judgments of relative importance are expressed through linguistic variables from the scale introduced by Yang and Chen (2004).

The main reference to design the experimental design has been Sforza (2002). However for what concerns the survey related to MADM the approach presented by Lahdelma et al. (2000) provides valuable clues. In particular it shows the way to identify the most relevant stakeholders and to provide them a questionnaire with elements that can be easily understood. 94 questionnaires have been emailed to academics and managers with a good knowledge of this topic. If after two weeks there was not any answer another email was sent.

At the end of this second run 22 experts filled the questionnaire. The sample includes 8 academics, 7 managers from utilities and 7 managers from main contractors building power plants all around the world.

Points 5-6. Table 3 presents the defuzzified weights obtained from the application of geometric mean and Buckley's methods. It also shows the best performing solution on each attribute and

final indexes (relative Euclidean closeness to ideal solution) for LRs and SMRs. The main goal of the table is to highlight which attributes promote LR choice in the default scenario, and which ones promote SMRs. The two-step process shows the best NPP in the default scenario is the LR.

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6. DISCUSSION

The goal of this research has been do develop and implement a method to integrate the results from the INCAS model about financial/monetary factors and external factors related to the LRs vs. SMRs.

First of all, expert opinions confirm that external factors and related classes are approximately as important as financial factors: so just traditional DCF methods would not be sufficient to guarantee the right choice between LRs and SMRs. In fact the most important aspect is the Local Population's Attitude (weighting 14.1% for the decision), which is an external factor. Even if it is one main topic in the nuclear debate, as expert elicitations underlined, population attitude towards LRs and SMRs is the same, because different designs and sizes are not perceived differently intrusive or risky. So, the "roughly equal" performance of SMRs and LRs makes "Local Population's Attitude" not differential. If the investors are able to communicate the higher safety and design robustness of SMRs, this factor could become differential to promote the SMR choice. However where NIMBY syndrome is strong, to find four different sites for SMRs is more difficult than a single LR site, since the solution of local oppositions requires a great effort in terms of "diseconomy of hassle" (Ingersoll, 2009), money and risk augmentation. In this case, public acceptance is differential and promotes few large power sites. As a consequence, considering four SMRs in the same site makes public acceptance not differential, even in the case of strong NIMBY syndrome.

According to table 2, LRs seem to perform better from the financial point of view, even if SMRs contribute to reduce financial risk thanks to their lower maximum outflow in the first phase of the project. On the other hand, 10 out of 12 external factors promote SMR choice in the default scenario; for example:

- During the planning and construction phases, more sites can be exploited, the time to market is shorter, there are less risks associated to the construction and a higher benefit for national industries. Due to the smaller dimension SMRs have the potential to develop a

wider supply chain with a higher number of suppliers inside national burdens. Investments to become an SMR supplier is more competitive.

- In the operational phase, SMRs provide more job positions and do not require additional costs in terms of spinning reserves. Fractioning the capacity if, in one hand increases the cost, on the other hand increases the job position and create a more flexible system.

However IRR and LCOE are very important (weighting almost 20% for the decision), so LRs can be put up as "best choice" thanks to:

- Higher Internal Rate of Return and lower need for equity (financial);

- Lower Leveled Cost Of Electricity;

It is important to point out that the difference between the score of the two technologies is really slight, therefore it is necessary to deeply investigate performances on attributes.

Sensitivity analyses show as the overall electric power to be installed is most important factor since influences all the financial factors. Decreasing the power from 13 to 7 GWe LRs perform as SMRs. Moreover the sensitivity analysis shows as there are several scenarios where SMR can be a reasonable choice respect to LR; among the other:

- SMR are competitive with LR when the power required is 3 GWe or less, because of the economies of scale are compensated by the "economy of multiples".

- In case of constrained financial resources the self-financing option and the reduced maximum required upfront investment required are strategic factors for relatively small utilities with limited budget.

- Where the environment represent a challenge in terms of water availability, earthquakes etc. because safety constrain become even more important.

- SMRs can represent the ideal solution for "new comers" without experience in building and operate nuclear reactors: to build and operate SMR is easier than LR (Locatelli and Mancini 2011).

7. CONCLUSIONS

Nowadays a significant interest towards SMRs is growing in several countries, including those economically and infrastructurally developed. Even the USA are interested in SMRs as recently confirmed by its Secretary of Energy, Dr. Steven Chu (Chu, 2010).

In SMRs the reduced size is exploited from the design phase to reach valuable benefits in safety, operational flexibility and economics. A rough evaluation based only on the "Economy of scale" could label these reactors as economically "not attractive". This approach is incomplete and misleading since the reduction in size paves the way to many advantages such as: new technical solutions, cost sharing, faster learning and additional strategic opportunities. All these aspects have been carefully analyzed and evaluated. Indeed, the main goals of these research activities has been achieved through the development of an integrated model, called INCAS able to support a systematic and comprehensive evaluation of SMR, merging economic and strategic objectives. INCAS performs an investment project simulation and assessment of SMRs and LRs deployment scenarios, returning economic and financial performance indexes (e.g. IRR, LCOE, total equity employed, etc.) along with external factors (e.g. design robustness, required spinning reserve, etc.). This is a great improvement since traditional DCF methods for the evaluation of investments are not able to consider external factors because of their qualitative and subjective nature. However such factors dramatically influence the construction and operations of each industrial plant. This holistic evaluations showed that there is not a clear preference toward LR or SMRs since some indicators (e.g. IRR, LUEC) are better in case of LRs, while other (design robustness, spinning reserves) are better in case of SMRs. Therefore it is necessary to integrate all the factors in a synthetic rank of the alternatives

Under this perspective the two–step process presented in this paper is a valuable tool to support the decision making process in selecting the plants given a certain scenario:

- In the first phase, fuzzy AHP will be used to obtain the importance weights of factors: it allows to consider expert opinion in the simplest and most efficient way;

- Resulting weights will be used for the integration of LRs and SMRs performances, on financial and external factors, through the TOPSIS method, a simple and understandable MADM technique. The final outcome is a unique, numerical and crisp index, which permits to rank alternatives. TOPIS integrate the expert judgments with the INCAS values for each single factors

In conclusion, respect to traditional AHP which considers only judgments of experts, this approach is able to include numerical performances on each attribute which are usually evaluated through specific models. It provides the best choice among a finite number of alternatives, and if results show a clear preference toward a certain project it can be considered a "robust solution", otherwise it is wise to better investigate the most relevant attributes.

ACRONYMS

AHP = Analytic Hierarchy Process

DCF = Discounted Cash Flow

ELECTRE = ELimination and Choice Translating REality

IAEA = International Atomic Energy Agency

INCAS = INtegrated model for the Competitiveness Assessment of SMRs

IRR = Internal Rate of Return

LCOE = Leveled Cost Of Electricity

LRs = Large Reactors

MADM = Multi Attribute Decision Making

MAUT = Multi Attribute Utility Theory

MCDM = Multi Criteria Decision Making

MODM = Multi Objective Decision Making

NIMBY = Not In My Back-Yard

NPP = Nuclear Power Plant

NPV = Net Present Value

PBT = Payback Time

PROMETHEE = Preference Ranking Organization METHod for Enrichment Evaluation

ROI = Return On Investment

SMRs = Small Medium Reactors

WTP = Willingness To Pay

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|	STRENGTHS	WEAKNESSES	REFERENCES
AHP	-Well-established method -Very flexible and able to fit many problems -Effective integration of qualitative and quantitative evaluations on attributes. -Pairwise comparisons approach permits a simple and effective expert elicitation of attributes' weights -It breakdowns every complex problem in simpler and hierarchical components, simplifying its understanding -It does not require a specific utility function for each attribute: performances of alternatives on attributes are elicited from experts -It measures the consistency of expert judgments	-To translate a complex problem in a hierarchical structure could be difficult and subjective -Pairwise comparisons require to express "*how many times A is more important than B*" -Each judgment must be expressed through the Saaty's 9 points scale, based on crisp numerical values -It requires too many judgments from experts if there are many attributes -Possibility of rank reversal	(Saaty 1980), (Hamalainen 1990), (Saaty 1990b), (Yoon and Hwang 1995), (Bharat and Barin 1996), (Korpela and Tuominen 1996), (Salo and Hamalainen 1997), (Zanakis et al. 1998), (Akash et al. 1999), (Adler 2000), (Al-Harbi 2001), (Cheng et al. 2002), (Greening and Bernow 2004), (Navneet and Kanwal 2004), (Agalgaonkar et al. 2005), (Figueira et al. 2005), (Kiker et al. 2005), (Vaidya and Kumar 2006), (Shin et al. 2007), (Saaty 2008).
FUZZY AHP	-It better represents the uncertainty of judgments than the traditional AHP, thanks to the overlapping between fuzzy variables which represent expert opinions -Decision maker's cognitive process is simpler: he uses linguistic variables to express judgments -It is the most efficient method for expert elicitations. It is also demonstrated by the many applications available in literature	-Comparison and ranking of fuzzy sets in the final evaluation are complex and unreliable -Hierarchical structures with more than three levels are difficult to be examined in a complete and comprehensive way -Measurement of consistency is more complicated with respect to traditional AHP	(Chang 1996), (Ribeiro 1996), (Beccali et al. 1998), (Cheng et al. 1999), (Deng 1999), (Zhu et al. 1999), (Leung and Cao 2000), (Kuo et al. 2002), (Kwong and Bai 2002), (Fan et al. 2004), (Hsieh et al. 2004), (Kahraman et al. 2004), (Yang and Chen 2004), (Chiou et al. 2005), (Ozdagoglu and Ozdagoglu 2007), (Wang et al. 2008), (Kahraman and Cebi 2009).
SCORING METH.	-Easy to understand	-The need for a unique integration function: the more heterogeneous attributes are, the more difficult to find it will be -It does not consider how an attribute can be further separated through multiple levels	(Dyer 1979), (Yoon and Hwang 1995), (Zanakis et al. 1998), (Adler 2000), (Figueira et al. 2005),
ELECTRE	-Well-established method -It is based on particular outranking relations, less restrictive than dominance relations -It provides for a decision matrix normalization and so every attribute can be expressed in its own unit of measurement -The outcome is a ranking, so it is easier to understand than AHP indexes	-More useful with many alternatives and few attributes (not the case of selection of the right NPP design) -Usually it identifies a restricted group of preferable solutions, instead of the best one -It considers only the number of attributes on which alternative A outranks B. It does not consider the real existing gaps on values -Decision maker must fix two thresholds edging performance on each attribute: their subjective values could seriously affect final outcomes	(Yoon and Hwang 1995), (Georgopoulous 1997), (Beccali et al. 1998), (Zanakis et al. 1998), (Pohekar and Ramachandran 2004), (Figueira et al. 2005), (Kiker et al. 2005).
PROMETHEE	-Thresholds for preference and indifference indexes permit to consider non-linear preferences -Thresholds permit to define different degrees of preference between two alternatives on each attribute	-More useful with many alternatives and few attributes -Thresholds are subjective and *decision-maker-dependent*. The higher number of parameters makes the method more complicated and less standardized	(Babic and Plazibat 1998), (Haralambopoulos and Polatidis 2003), (Pohekar and Ramachandran 2004), (Cavallaro 2005), (Figueira et al. 2005), (Kiker et al. 2005), (Nowack 2005).
TOPSIS	-It is intuitive and easy to understand -It provides for a decision matrix normalization and so every attribute can be expressed in its own unit of measurement -It considers both similarity to a positive ideal solution and distance from a negative ideal one -It considers the real existing gap between values of different alternatives, and it does not only count the number of outranked attributes	-More useful with many alternatives and few attributes -To consider positive and negative ideal solutions could be meaningless for some applications.	(Hwang and Yoon 1981), (Yoon and Hwang 1995), (Zanakis et al. 1998), (Opricovic and Tzeng 2004), (Figueira et al. 2005).

Table 1 – General strengths and weaknesses of MADM methods

|	METHOD	STRENGTHS	WEAKNESSES
1st step - Weights Elicitation	AHP	-There are dedicated software which simplify elicitation from experts and final ranking	-It does not take into account the uncertainty associated with the mapping of human judgment to a number (Yang and Chen 2004). Experts must give **crisp numerical** judgments of relative importance for each attribute on each other -Experts must judge "**how many times**" an attribute is more important than another
	Fuzzy AHP	-Experts have not to express "**how many times**" an attribute is more important. They express their opinion through simple linguistic judgments: questionnaire is easier to understand, faster to be filled out and so resulting weights are more accurate -Overlapping of fuzzy judgments well considers uncertainty and vagueness of the subjective perception	-Mathematic elaboration is more complicated, but only if method is used for the final integration (2nd step) -No dedicated software -Less experienced method, both in theory and real case applications.
2nd step – Final Integration	Scoring Meth.	-Simple and easy to understand	-It is difficult to find a unique function able to represent the relationships among performances
	ELECTRE	-Decision makers can customize the process fixing different thresholds for the indexes	-Thresholds strongly affect the final ranking and make it subjective, requiring too much information from decision maker -More useful with many alternatives and few attributes
	PROMETHEE	-Decision makers can customize the process fixing different thresholds for the indexes	-It requires the elicitation of a preference and an indifference threshold value for each attribute. Process is more complicated and the higher request for information does not guarantee a better ranking of designs, considering that decision maker is dealing with ballpark estimates in selection phase.
	TOPSIS	-Simple and easy to understand -It considers the effective difference between values on each attribute for different NPP designs -Every performance can be evaluated using its specific unit of measurement - It does not require more information, threshold values or parameters from decision maker. The process is simpler and less subjective.	- More useful with many alternatives

Table 2 – Critical review of MADM methods for "Selection of the best NPP design"

ATTRIBUTE	Class of factors	Weights of class	Weights of attributes in the class	Absolute weights of attributes	Best performance
IRR	Financial related	30,1%	29,7%	8,9%	LR
IRR variance			20,7%	6,2%	Roughly equal
Payback Time			20,1%	6,1%	Roughly equal
Equity employed			17,2%	5,2%	LR
Max cash outflow			12,4%	3,7%	SMR
Spinning reserve	Site related	24,9%	7,4%	1,8%	SMR
Grid vulnerability			13,2%	3,3%	SMR
Local population's attitude			56,5%	14,1%	Roughly equal
Technical siting constraints			23,0%	5,7%	SMR
Time to market	Welfare related	24,0%	15,0%	3,6%	SMR
Impact on employment (construction)			5,8%	1,4%	SMR
Impact on employment (operational)			5,8%	1,4%	SMR
Impact on national industrial system			20,5%	4,9%	SMR
Leveled Cost Of Electricity			53,0%	12,7%	LR
Risk associated to the project	Project Life Cycle related	21,0%	33,0%	6,9%	SMR
Design Robustness			22,1%	4,6%	SMR
Historical and political aspect			32,2%	6,8%	LR
Competences required for operations			12,8%	2,7%	SMR
Final Index C_{SMR}		**0,4623**	The best solution has the highest value of C: LRs are slightly better		
Final Index C_{LR}		**0,5377**			

Table 3 - Weights and final integration results for best NPP technology
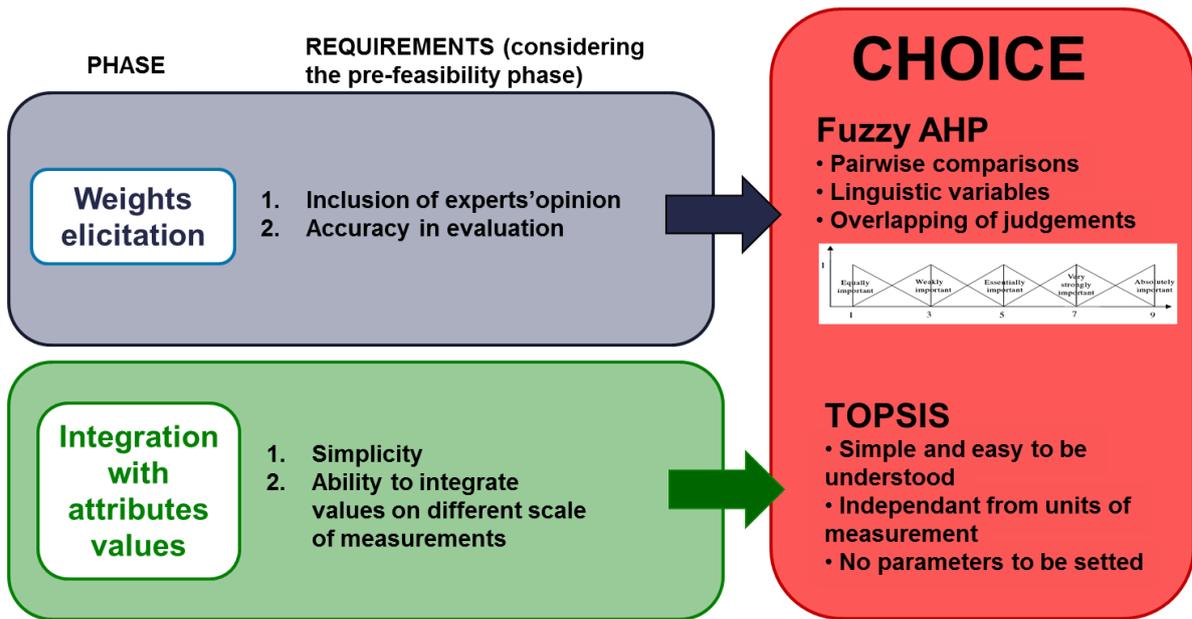
Figure 1 – Selections criteria
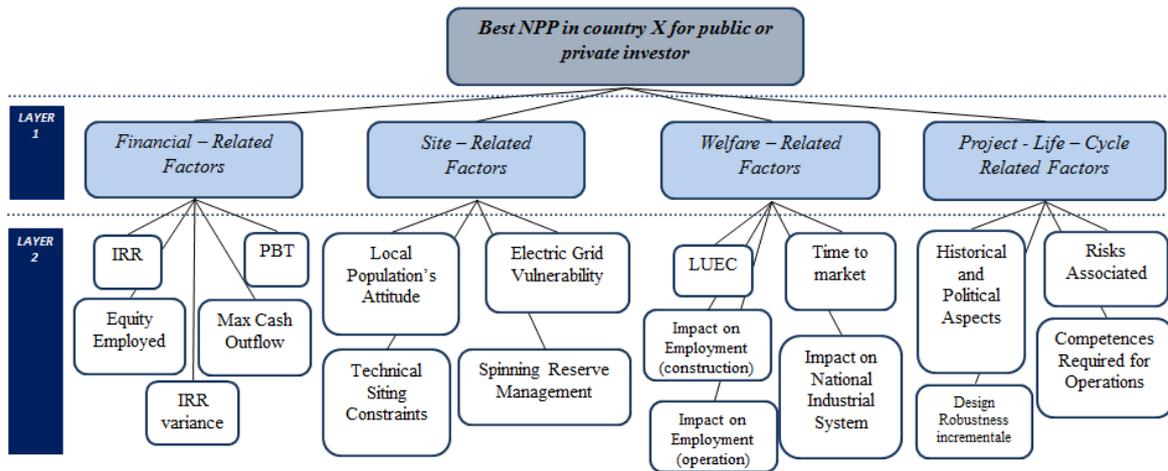
Figure 2 – Hierarchical structure for weights' elicitation using fuzzy AHP