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MULTI-CRITERIA EVALUATION OF NUCLEAR OPTION

SUMMARY

When evaluating power system expansion scenarios there is a need to take into consideration a range of measurable and non-measurable impacts. Measurable impacts are fixed and variable production costs and, recently, external costs. Non-measurable impacts include public attitude to a certain energy technology and investor's risk in achieving the expected profit. Public attitude has a large, and sometimes essential impact on decision-making and can be divided in objective and subjective part.

Investor's risk in achieving the expected profit is mostly associated with possible changes of domestic or foreign regulations or policy that can influence power plant operation and long-term fuel availability and price.

The objective of multi-criteria evaluation, after weighting and quantification of all impacts, is to determine the most acceptable power system expansion option.

In the article a simplified quantification was made of measurable and non-measurable elements that affect future investment decision. For that purpose possible relative values of non-measurable impacts of different options will be determined (their weights and impact on relative increase of annual costs).

Four possible technologies will be compared: nuclear power plant, coal power plant, combined cycle gas plant and wind power plant in combination with gas plant.

The expected change of non-measurable impacts on investment decision in the period 2010-2030 was analysed as well as the influence of those changes on future investment decisions.

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Key words: Multi-criteria evaluation; Power Plant; Nuclear option; Investment cost; Competiveness

1. INTRODUCTION

Inadequate power system expansion plan can lead to great difficulties in system operation or large expenses in the future. Therefore it is a very serious and responsible task where all the possible different impacts should be included in decision-making process. For many years the most important and sometimes the only criterion in planning were costs. It is not possible to make an expansion plan only on the basis of least-cost planning any more. Many other criteria become important, and will be more important in the future and multi-criteria methods are essential in evaluation of different options.

The multi-criteria decision making (MCDM) process should be made in several steps [1]. Different methods of MCDM define different steps but we will use a simple five-steps method:

1. Attributes (criteria) selection
2. Definition of options (alternatives)
3. Weighting the attributes
4. Quantifying impacts
5. Amalgamation

The first step in MCDM is attribute selection. Selecting issues to be included in planning may be one of the most difficult tasks. Selected attributes (criteria) often reflect who participates in the decision making process, they reflect perception about what is important. When evaluating power system expansion scenarios there is a need to take into consideration a range of impacts but here will hold on four groups: costs, environmental impacts, public attitude and risk.

The objective of MCDM is to choose the "best" option among all possible options. As "all possible options" can be a huge number of them the next step is to make a set of reasonable number of options to choose from. In this paper we evaluate nuclear option against some other energy options.

Weights of attributes show how much certain criterion is important for decision maker. They show for example if environmental issues are of a great concern or the public opinion is more important. Quantifying impacts of different options should be done very carefully and as much objective as it can be done.

A difficult and sometimes controversial task in MCDM is to amalgamate different impacts into a single value. But expressing different impacts with the same unit of measure and aggregate impacts

2. IDENTIFICATION OF ATTRIBUTES AND OPTIONS

The major objective in power system expansion planning is to minimize costs. Years ago it was realized that cost minimization does not take into consideration other impacts of energy production that should be considered, primarily the environmental impact. All energy technologies produce some negative impact to the environment but the problem was how to evaluate it. One often used method for evaluation of environmental impact is the method of external costs where the damage to the environment and human health is monetary valuated. Extern costs are shown to be a quite good method although monetary valuation of environmental impact is still a controversial issue and there is no generally acceptable method of evaluation. The emissions from thermal power plants can be determined precisely, their impact to human health not so precisely, but the major problem is the valuation of human health. On the other hand extern costs don't take into consideration other impacts and they are shown to be inadequate as a power system expansion planning method and multi criteria decision making can be considered as a step forward in planning methods.

As the result of democratization process public opinion have more and more importance and its impact to decision making becomes greater, sometimes essential. This impact can be divided in objective and subjective part. Objective part, which is in proportion with scientifically approved environmental impact of energy options (inversely proportional to external costs) is relatively small, while the other, subjective category which is not proportional with the actual environmental impact (especially in the case of nuclear power), is much larger.

The electricity sector in many countries is in some kind of restructuring (deregulation, privatization, liberalization etc.). Regulation and "rules of the game" are changing and that brings uncertainties for investors of new power plants. Another uncertainty is the future fuel prizes and their availability. All those institutional, political or economic uncertainties bring the risk for investor's expected profit and should be included in the decision making process.

There are also other attributes that can be consider (between five and fifteen attributes are typical for energy sector applications) but in this paper we will hold on these four:

1. Costs (direct and indirect)
2. Environmental impact (external costs)
3. Public impact (objective and subjective)
4. Investor's risk (change of regulation, availability and cost of fuel)

Costs are "measurable" impacts, we can calculate them. Environmental impact became "measurable" trough the method of external costs. But many other impacts are not measurable and cannot be easily monetary expressed. We call them "non-measurable impacts". Quantifying different non-measurable impacts needs expert judgment on the importance of certain impact and determines the specific MCDM model. Monetary valuation of different impacts is quite controversial issue but it's still the best and the most used method in MCDM. This method aggregates all the impacts into the single number, enabling an easy comparison of different options.

3. WEIGHTING THE ATTRIBUTES AND QUANTIFYING IMPACTS

A method for evaluating the environmental impact through external costs is used in this paper. However the external costs are weighted with the factor of 0.5 that means that external costs impact is weighted as 50% of direct costs impact. Sum of internal costs and 50% of external costs are called the total costs. In this paper we use the ratios of different impacts, and then compare them to the total costs as the basic criterion (relative impact set to 1). Total cost impact is valued as 50% of total impact, and for example the investor's risk concerning change of regulations 15%. That leads us to relative impact of 0.3. All the attributes with their weights are shown in Table I.

This step does not yet present the evaluation of options because they are not yet determined. The table just shows the decision-maker's attitude to different attributes in decision-making process. Decision-maker determines those weights and they show how much certain criterion is important to him.

Table I. Weights of attributes

Attribute		Percentage of impact	Weight
Direct costs		40%	1
External costs		20%x0,5=10%	
Public impact	Objective	2%	0,04
	Subjective	18%	0,36
Investor's risk	Changes of regulations	15%	0,30
	Availability and cost of fuel	15%	0,30

In every decision making process there are different options to choose from. Important step is to define well a reasonable number of options that shows meaningful difference in type of option and its impacts. Evaluation of nuclear option is done in comparison with other energy technology options. Those options are coal power plant, combined cycle gas power plant and combination of wind and gas (CC) power plants. This should be a reasonable number of reasonable options for the purpose of this paper but in the real evaluation of energy options the number of options (and criteria) should be larger.

Impacts of different options are quantified relatively to the largest impact. Subjective public impact is the largest in nuclear option and it is set to be 1. Weights for other energy technology options are evaluated in comparison with that one. Subjective public impact is large also in coal option (weighted as 0,9) and it is significantly lower in gas (0,3) and wind+gas (0,2) option. Prizes and availability of gas are the most uncertainly among examined options, while for nuclear and coal fuel that risk is weighted as 10% of risk in gas option. All weights are shown in the Table II.

Table II Quantification of impacts of different energy options

Power Plant Technology		Coal	Gas	Nuclear	Wind + Gas
Public impact	Rational	1,0	0,5	0,1	0,2
	Non-rational	0,9	0,3	1,0	0,2
Investor's risk	Change of regulations	0,7	0,2	1,0	0,4
	Availability and cost of fuel	0,1	1,0	0,1	0,7

When attributes are weighted and impacts are quantified we can calculate the total relative values of non-measurable impacts as the product of those two values. As we weighted impacts in comparison with total costs these values represents relative increase of total costs and they are presented in Table III.

Table III. Relative increase of total costs

Power Plant Technology		Coal	Gas	Nuclear	Wind + Gas
Public impact	Rational	0,040	0,020	0,004	0,008
	Non-rational	0,324	0,108	0,360	0,072
	Total public impact	0,364	0,128	0,364	0,080
Investor's risk	Change of regulations	0,210	0,06	0,300	0,120
	Availability and cost of fuel	0,030	0,30	0,030	0,210
	Total investor's risk	0,240	0,360	0,330	0,330
Total increase of annual costs		0,604	0,488	0,694	0,410

Investor's risk and the public impact will increase costs of new coal power plant for 60,4%, gas plant for 48,8%, nuclear power plant for 69,4% and new gas and wind power plants for 41%. It is important to notice that these cost increments are not the real costs, it is just the measure of what we called "non-measurable" impacts in the decision making process. Cost increments for all options with shares of different impacts are shown in the Figure 1.

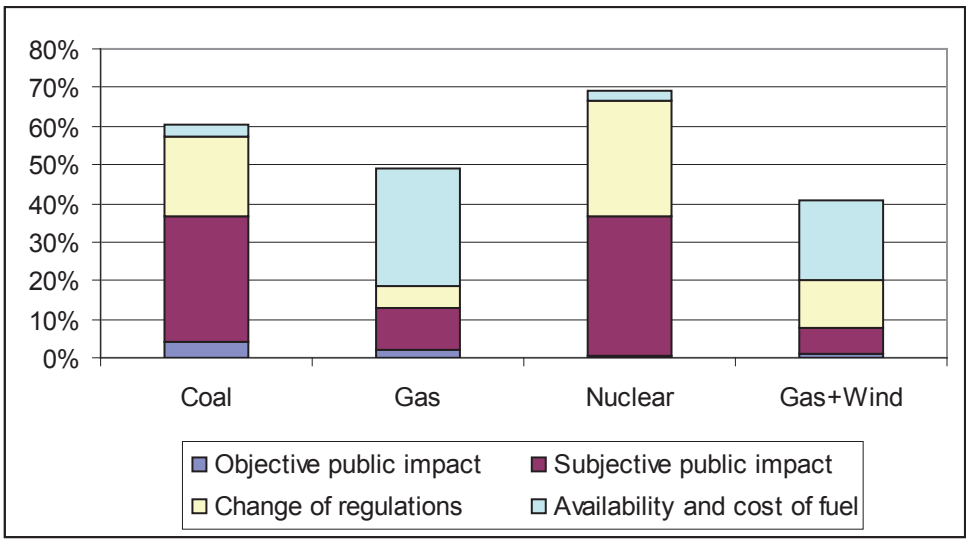

Figure 1. Cost increments

In Table IV a calculation for four candidate 600 MW power plants is presented [2]. When only direct costs are evaluated the gas option is shown to be the cheapest. If we include the extern costs (50% of them) that represent the environmental impact the best option is nuclear. But, when all the non-measurable impacts are included, nuclear option loses its first position and gas is again taking it. The most expensive option (wind+gas) in this case is very near to coal option although direct costs are almost 80% higher. Both options are more than 40% worst than the nuclear option.

The construction period of a new power plant is long, from several years up to seven or even more, depending on technology and other circumstances than can occur during the construction. The lifetime of new power plants is usually 40 or more years and the return of investment is usually from 15 to 30 years. The factor of time is therefore very important in evaluating the projects in energy sector and it has to be taken into the consideration during the decision making process.

In a long-time period different impacts in MCDM will not preserve the same importance. A time period until 2030 is analyzed here and it is divided in three subperiods. Different weights of attributes and impacts of different options are assumed in each subperiod. It is expected that the objective public impact will increase due to spread of knowledge and better understanding of the matter in the public. On the contrary, the subjective impact will decrease. This can be expected because the general public is becoming more concerned and involved in the energy policy matters.

As mentioned above, the electricity sector in many countries is in some kind of restructuring and uncertainties caused by the change of regulations are high. It can be expected that in the next decades when this process will be finished and the liberalized electricity market completely established and functioning, this impact will decrease. On the other hand the risk concerning the availability and cost of fuel in the future will significantly increase.

Table IV. Investments, annual O&M costs, fuel costs and indirect costs of power plants

Power Plant Technology	Coal	Gas	Nuclear	Wind + Gas
Capacity (MW)	2x300	3x200	600	600x1+3x200
Investment costs (USD/kW)	1500	600	2000	2800+600=3400
Fixed O&M costs (USD/kW-year)	35	12	100	wind 24, gas 12, average 18
Investment rate (percent, number of years)	7%, 20yr	7%, 15yr	7%, 20yr	7%, 15yr
Life time (years)	30	30	40	30
Annual capital costs (USD/kW)	141,59	65,87	188,78	373,30
Total annual fixed costs (USD/kW-year)	176,59	77,87	288,78	391,30
Fixed Costs (USD/MWh-year)	23,6	10,4	38,8	52,6
Fuel cost (USD/MWh)	16	31	5	0,65/0,85x31=23,7 (for wind LF=0,2)
Variable O&M costs (USD/MWh)	4	2	2	1
Total variable costs (USD/MWh)	20	33	7	24,7
Total annual direct costs (USD/MWh)	43,6	43,4	45,8	77,3
Extern costs (USD/MWh)	60	20	7	2/3x20+1/3x3= 14,3
Total costs (direct+50% extern) (USD/MWh)	73,6	53,4	49,3	84,45
Increase factor of total costs	1,604	1,488	1,694	1,410
Increased total costs (USD/MWh)	118,1	79,5	83,5	119,1
Relative costs (NPP=1)	1,414	0,952	1,000	1,426

Total annual costs are weighted as 50% of total impacts in all subperiods. All impacts to power plant investment decision and their relative increase of total costs in period until 2030 are shown in Table V.

Table V. Expected change of attribute weights until 2030

Period			until 2010	2010-2020	2020-2030
Public impact	Objective	Impact	2%	4%	7%
		Weight	0,04	0,08	0,14
	Subjective	Impact	18%	11%	8%
		Weight	0,36	0,22	0,16
Investor's risk	Change of regulations	Impact	15%	10%	5%
		Weight	0,30	0,20	0,10
	Availability and cost of fuel	Impact	15%	25%	30%
		Weight	0,30	0,50	0,60

In Table VI we quantified impacts of different technology in three subperiods. Subjective public attitude toward nuclear option it is assumed to be slightly better in the next decades and therefore the impact factor is lower. Risk of change of regulation in all options is lower in the next decades.

Table VI. Expected change of non-measurable impact factor to power plant costs until 2030

Technology	Coal			Gas			Nuclear			Wind + Gas		
Period	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030
Public impact												
Objective public impact												
Impact factor	1	1	1	0,5	0,5	0,5	0,1	0,1	0,1	0,2	0,25	0,3
Cost Increase Factor	0,04	0,08	0,14	0,02	0,04	0,07	0,004	0,008	0,014	0,008	0,020	0,042
Subjective public impact												
Impact factor	0,9	0,9	1	0,3	0,3	0,3	1	0,8	0,7	0,2	0,2	0,2
Cost Increase Factor	0,324	0,198	0,16	0,108	0,066	0,048	0,36	0,176	0,112	0,072	0,044	0,032
Investor's risk												
Change of regulations												
Impact factor	0,7	0,5	0,3	0,2	0,15	0,1	1	0,8	0,6	0,4	0,3	0,2
Cost Increase Factor	0,21	0,1	0,03	0,06	0,03	0,01	0,3	0,16	0,06	0,12	0,06	0,02
Availability and cost of fuel												
Impact factor	0,1	0,1	0,15	1	1	1	0,1	0,15	0,2	0,7	0,8	0,9
Cost Increase Factor	0,03	0,05	0,09	0,3	0,5	0,6	0,03	0,075	0,12	0,21	0,4	0,54

Total costs of different technologies are calculated in Table IV and in Table VII we can see the influence of non-measurable impacts to those costs.

Table VII. Costs of different power plants until 2030

Technology	Coal			Gas			Nuclear			Wind + Gas		
Period	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030	until 2010	2010-2020	2020-2030
Total costs (USD/MWh)	73,6			53,4			49,3			84,45		
Increase factor of total costs	1,604	1,428	1,420	1,488	1,636	1,728	1,694	1,419	1,306	1,410	1,524	1,634
Increased total costs (USD/MWh)	118,1	105,1	104,5	79,5	87,4	92,3	83,5	70,0	64,4	119,1	128,7	138,0
Relative costs (NPP=1 in the first subperiod)	1,414	1,259	1,251	0,952	1,047	1,105	1,000	0,838	0,771	1,426	1,541	1,653

How much will total increments of costs due to the measurable impacts change for different energy technologies can be seen in the Figure 2. Although these non-measurable factors have the greatest impact on nuclear option it is expected that they will decrease the most in next decades what will make the nuclear option much more competitive.

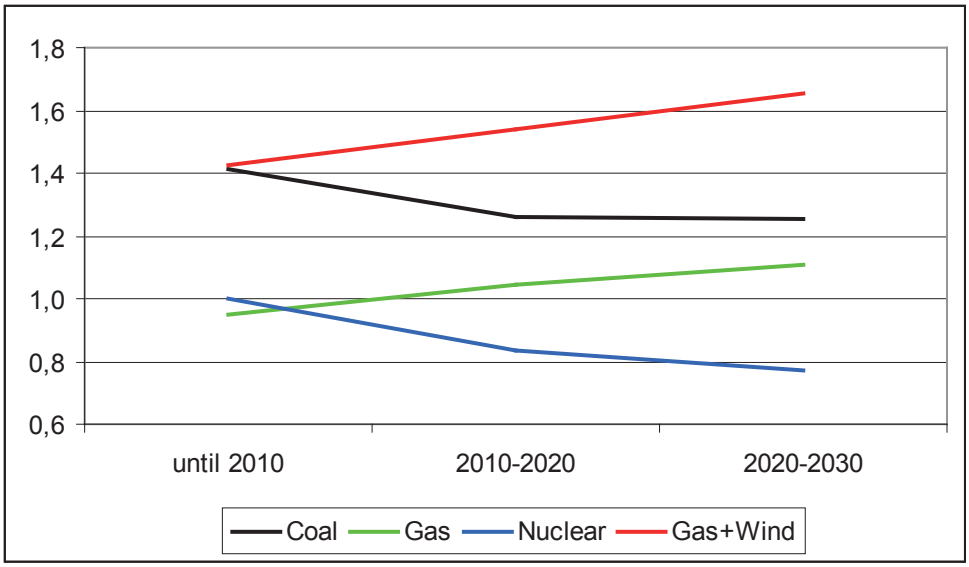

Figure 2 Relative acceptance indicators of different power plants up to 2030

The long-term competitiveness evaluation shows decrease of gas power plants competitiveness, mostly caused by investor's risk due to possible change of fuel availability and price. It also shows an increase of NPP competitiveness caused by

expected decrease of public disagreement and decrease of investors risk concerning change of regulations.

4. CONCLUSION

A simple multi-criteria evaluation of nuclear option is done. Different impacts are divided in "measurable" (intern and extern costs) and "non-measurable" (public attitude and investor's risk) impacts. Non-measurable impacts are weighted and expressed in terms of measurable costs. In that way a simple amalgamation of results and easy comparison is possible. A long-term evaluation is also done and the results show that NPP competitiveness will increase in the future.

Improvements of method can be done by taking into consideration more possible impacts and more different options and of course better judged impacts. The change of methodology itself is also possible.

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