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Real Options Analysis of Electricity Portfolios

SUMMARY: The characteristics of large, sometimes giga-sized investments of complex engineering systems often require a multidisciplinary decision-making process. The investment parameters on which the decision-making is based, the optimality criteria underlying this process and the identification of the parameters of evaluation models also require mutual cooperation between engineering and economic professionals. Using methodological analysis and empirical testing of capacity planning in the power generation sector, I tried to knock holes in the preconceptions almost cast in stone which argue that traditional technologies decisively dominate renewable technologies under any circumstances, or that the stars in the paradigm shift that is taking place in the industry can be nothing else but renewable technologies. In order to prove this hypothesis, I choose real options and portfolio theory as a verification tool, as I consider these theories as methods that are capable of capturing all the factors behind the optimal power generation mix. The empirical results and qualitative arguments of this study demonstrate that real options theory along with portfolio theory can provide capacity planners with the most advanced optimisation tool for power generation mixes through taking advantage of the benefits of diversification and flexibility.¹

KEYWORDS: real options, uncertainty, flexibility, energy mix, interaction

JEL CODES: G31, G32

The present study assesses the drivers of manager decisions which are built on the evaluation of irreversible investments in the electricity sector exposed to significant and increasing uncertainties as a consequence of changes in market conditions and consumer and regulatory expectations, and which are actively seeking, recognising and utilising temporal and operational flexibility, especially in view of planning the electricity mix for investment.

In the third millennium, most developed countries have turned away from nuclear technology, primarily in view of its cost, social acceptance as well as its alleged hazards and vulnerability. The world saw renewable technologies of power generation as an unlimited source of energy and an opportunity for cre-

ating new enterprises and jobs, reducing dependence on external resources and, last but not least, driving down greenhouse gas emission.

However, it soon turned out that power plant operators, threatened by uncertain market conditions and their competitors in addition to the newly emerging technologies and focusing on maximising their profit, were unwilling to accept the trade-off between their current profit and future external benefits (not reflected directly in cash-flow). In addition, only very few of the notoriously price-conscious consumers were willing to yield to the pressure of environmental awareness. The legislators had to fill the role of acting as a mediator between the two actors, making the consumers interested in using the services of a more sustainable energy system and motivat-

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ing the generators to create an electrical energy mix that is still acceptable for the consumers in terms of costs and which is optimal in terms of both profitability and environmental criteria.

In my research, using methodological analysis and empirical testing of capacity planning in the power generation sector, I tried to knock holes in the preconceptions almost cast in stone which argue that traditional technologies decisively dominate renewable technologies under any circumstances, or that the stars in the paradigm shift that is taking place in the industry can be nothing else but renewable technologies. In order to prove this hypothesis, I choose real options and portfolio theory as a verification tool, as I consider these theories as methods that are capable of capturing all the factors behind the optimal power generation mix. I conducted my analysis from the viewpoint of electricity producers. I selected the following ten power generation technologies for empirical research: coal-, oil-fired power plants, combined-cycle gas turbine (CCGT) power plants, nuclear power plants, wind parks, biomass power plants, natural gas-fired CHP cogeneration power plants, solar PV (photovoltaic) cells, solar thermal CSP (concentrated solar power) plants, and geothermal power plants. The purpose of this study is to present the complex dynamism of investments characterising the electricity sector by using a portfolio theory and real options framework which is built on mathematical modelling. I use and create cost- and yield-based models (by partially taking a stochastic approach into consideration) which can support the investment decisions of generators operating in an increasingly uncertain environment. Another declared goal of this paper, in addition to supporting optimal investment decision making, is to provide an output analysis of the model that influences the supply and demand for power generation technologies.

OPTIMALITY

Initially, reliable and secure supply of power rather than aspects of economy were in the focus in capacity planning. As shown by *Chart 1*, this goal did not disappear with the appearance of cost minimisation; the need for cost minimisation and profit maximisation was simply added to the overall goal, which is now determined by the ability to capture strategic value, as well as taking into account price-effectiveness, reliability, security, flexibility, environmental considerations, social acceptance and the existing generation capacities.

Accordingly, I considered the security of supply, cost minimisation and profit maximisation as goals of optimisation determined by competing and constantly changing parameters characteristic of the sector that cannot be delimited in space and time.

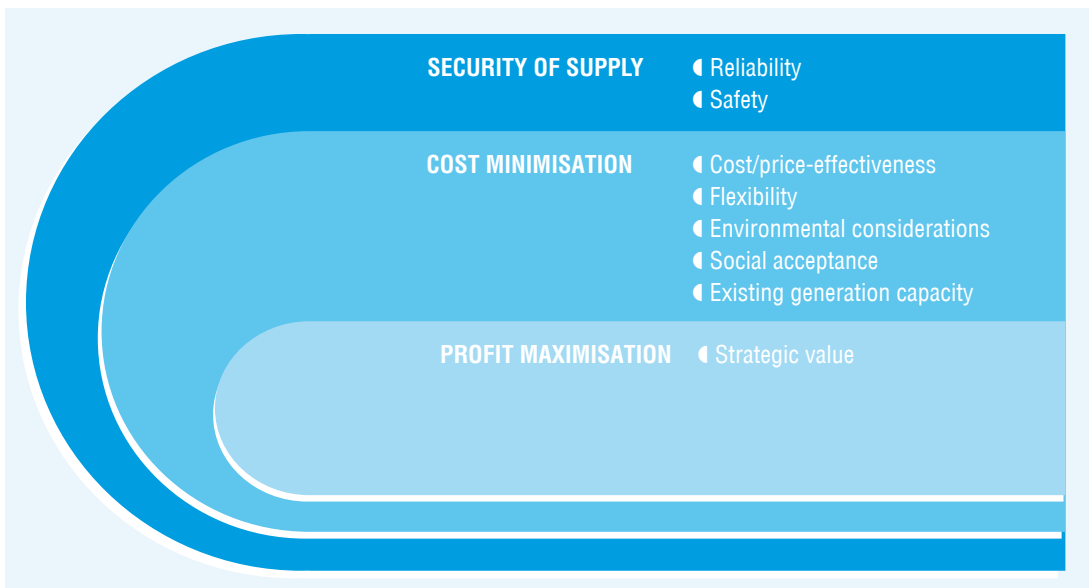
THE PORTFOLIO APPROACH IN THE ELECTRICAL ENERGY SECTOR

When the Markowitz model of portfolio theory had reached its peak of success in the area of financial instruments, there was an increased demand emerging within the liberalised electricity sector for methods that could handle a set of risks with more extensive and increasingly threatening uncertainty factors. The use of portfolio theory to define the optimal composition of real capital assets makes it possible to consider the risks related to future costs and revenues as well as the interactions between the various technologies both from the regulator's and the consumer's point of view, but only from a single viewpoint at a particular time.

In my view, it was at this point that the planning of electrical energy supply ultimately deviated from the requirement to identify a single option with the lowest cost and began,

Chart 1

OPTIMALITY CRITERIA IN THE ELECTRICITY SECTOR



Source: author's own editing

instead, to focus on the identification of efficient electricity generation portfolios.

The use of portfolio theory can contribute to improving the reliability and security of the electricity mix through minimising the (cost) risk of each technology, where improving security in my interpretation means reducing the risk of unexpectedly rising electricity costs rather than unexpected disturbances in power supply. By identifying efficient portfolios, the method is suitable for the evaluation of the benefits of diversification between technologies, so it is the first to bring some results in meeting the optimality criteria of flexibility. In other words, portfolio theory can identify an electrical energy mix which represents a higher degree of optimality.

OPTIONALITY IN THE ELECTRICAL ENERGY SECTOR

The electrical energy sector is a particularly interesting domain for real options analysis

due to the mix of the significant degree of uncertainty surrounding its investments and the potential of combining the interaction between high sunk costs and investment timing flexibility. According to the central premise of real options theory, managers' decisions focus on the creation of options that increase flexibility and reduce uncertainty, and then on calling (enforcing) or not calling (not enforcing) these options. If we are able to recognise, create and use real options – with this double ambition in mind –, we can not only improve our resilience to risks, but also increase our shareholder value in the long term as a result of a lower cost structure or a higher level of revenues (Arnold and Shockley, 2003).

When experts use real options theory for their decisions on investment, they are not examining a single real option but a multitude of options, that is, a portfolio of real options. The case of real assets requires an initial framework that is more extensive than portfolio theory since the task is no less than having to capture the interactions between the set of

real assets and the set of real options embedded in real assets when examining these two sets. Moreover, in many cases there are complex multiple options that interact with one another involving the same assets.

Nearly fifteen years after the first comprehensive references appeared in the literature (Dixit – Pindyck, 1994; Trigeorgis, 1996), real options theory has grown into a carefully elaborated and widely accepted theory in the evaluation of individual projects. Although the interaction between real options targeting the same asset was already addressed in *Brennan and Schwartz* (1985), *Kulatilaka* (1995), and *Dixit and Pindyck* (2000), the comprehensive analysis of real options in portfolio theory, that is, research focusing on the interaction between options targeting different real assets and their quantification has until now been relegated to the background. However, the assessment of a particular investment opportunity in a risky world has to consider the stochastic correlation of the given opportunity with all other options. All this means that we can only identify an optimal global strategy if we consider every relevant alternative concurrently (Franke – Hax, 1998).

The various publications and attempts mainly focused on a particular problem when it was absolutely necessary for them to consider the interactions and they were not explicitly looking at the phenomenon of interaction itself. Particularly noteworthy among these papers are the works of *Trigeorgis* (1993) and *Kulatilaka* (1995) who examined the interaction between options and pointed out that a multitude of real options within a project should not be evaluated separately. *Kester* (1993) looks into the case of consecutive product introduction (growth real options) which results in synergies and a learning effect. *Childs et al.* (1998) examined two projects which can be developed in parallel but only one of them can be implemented. Although these studies

addressed the portfolio of real options, none of them explicitly examined the problem of evaluating the portfolio of real options.²

Learning effect

The analysis of real options reveals that there is a learning effect in the form of information spill-over effects on other assets. *Dias* (2006) extends portfolio theory to real options, focusing on the role of correlation in synergies and learning when analysing crude oil exploration portfolios. According to him, the portfolio approach helps to understand the role of the learning effect, the synergies between two or more assets and the consequences of options to defer for portfolio planning. Learning here means the creation of a positive externality for another asset by calling an option in such a way that the utilisation of the first opportunity makes the other one more or less attractive.

Synergy effect

The examination of the entirety of real options and calling them sequentially or at the same time result in a kind of synergy effect due to the economy of scale and diversity. The indivisibility of projects and other practical factors (need for resources) require adequate intertemporal portfolio resource planning in order to ensure the optimal calling of real options (Dias, 2006). According to the synergy between two real options, the combined real option value is greater than the sum of the value of each individual real option. This means that for example we can consolidate R&D investments by increasing their scale in order to take advantage of the synergies between the projects, increasing the real option value of the unified development. The exploration option

is a complex real option since if it is called and is successful, we get another option, which is the option to exploit the discovered oil field, where the implementation of one investment has an influence on the other one.

Value additivity

First one would think that real options have value additivity, just like financial options, which means that in general the value of the total assets is equal to the sum of the value of each asset. This principle has been applied successfully both for financial assets and for the evaluation of investment projects in determining capital budgets. However, this is a wrong assumption in the case of real options. Financial options embody the distribution rights of a certain amount of basic products the value of which is typically independent of the existence of the option itself. In contrast, real options are often inseparably linked to the basic product since the ownership right of the basic product is a precondition for possessing the option and, as a result, the calling of the option will have an influence on the value of the basic product.

Diversification effect

According to the Markowitz-type portfolio selection model, as long as there is no perfectly positive correlation between the yields of securities under investigation, the risk can be reduced by diversification, that is, the relevant parameter of portfolio analysis is the direction and strength of comovement. Moving away from investment decisions, the investment programme of a company is nothing else but a set of real asset investments in which diversification will become a relevant factor, given that the cash-flow profile of separate projects

is typically not characterised by a perfectly positive correlation. If a new project is added to the portfolio, the aggregate risk of the portfolio will typically increase less than the separate risk of the project.

Although diversification, implicitly the correlation between the market value of individual projects without functional option, cannot be regarded as a relevant aspect of the portfolio, it becomes relevant in the case of real options when the new market value created by unifying the separate projects and the functional option is examined.

Direct qualitative interactions

Following the classification of *Betge* (1995), direct qualitative interactions are relations whose origin should be found in the investment plan³ or in the interactions between the investments that have already been commissioned but are still generating cash-flow. These direct qualitative interactions do not stem from stochastic relationships but from the physical properties of the project. In other words, unlike diversification, these can by no means be disregarded.

Projects with the same technical features and function are called mutually exclusive projects, which means that from the point of view of direct qualitative relations they should be seen as strictly replacing one another. For a given product line, a particular project may require the simultaneous existence of other projects. In investment terms, these are called dependent projects and in terms of qualitative relations they are projects strictly complementing one another.

However, real life can produce other, transitional relations apart from these two extremes. Gradual relations mean when the cash-flow profile of a project is positively and/or negatively influenced by the existence of other

projects. For example, there is positive gradual correlation for a power plant, the productivity of which increases due to the synergies with the other power plants. These interactions may be mutual or unidirectional. There is an interaction between two power plants if both can benefit from the synergy, and the relation is unidirectional if one of the power plants is not influenced at all by the existence of the other one. Of course, other combinations can be imagined, such as two power plants where one of them is positively, while the other one is negatively affected by the existence of the other one.

In summary, these interactions may influence both the profitability and the feasibility of projects. Naturally, as shown by the literature on investment theory, there may be no interaction whatsoever between projects; in this case, we are dealing with independent projects. In the next section, following *Hax* (1985), I will focus on projects strictly complementing one another since in a strict sense these are the kinds of projects for which it is worth examining interactions.

Indirect qualitative interactions

This kind of interaction can be considered qualitative because it is not a consequence of stochastic relations. It is indirect because it results from general circumstances and limitations that are not inherent features of investment projects and therefore they could be avoided, e.g. by exploring additional funding resources (Brosch, 2001).

The indirect qualitative interaction covers the qualitative interactions arising from the lack of coordination among power plants. Due to the lack of perfect harmonisation among power plants, the projects competing for limited resources and the interactions created by this competition may result in a bot-

tleneck even for a single power plant. These interactions (limited resources, budgetary restraints) go beyond the competence of the expert responsible for investment planning. Because the funding resources are limited, not all projects can be supported.

In this context, limited funding resources are the same as scarcity interpreted for any other plan.⁴ The relevance of portfolio aspect stemming for indirect qualitative interactions is not clear in the literature either. On the one hand, when we assume limited plans, we are creating joint models for the dynamics (interactions) between current plans, investment alternatives and future plans, which go beyond the scope of this study. On the other hand, the friction between the relevant markets or the organisational structure established by a company of its own free will may result in direct interactions that are hard to describe even in an otherwise perfect world (Trigeorgis, 1996). We either try to approximate these interactions, which in general leads to suboptimal results due to its difficulty, or we disregard their existence and qualify them as irrelevant. In order to simplify the complexity of the modelling task, I chose the latter in the next section and did not examine indirect qualitative interactions.

Interactions between options

In order to be able to understand the interactions between options, let us take two European-type real options for the same basic product with a different maturity. The real option with a shorter maturity is the first option, while the one with a longer term is the second option. The two options must be evaluated at the same time, although the value effect exerted on the two options can be demonstrated separately in a static manner (Trigeorgis, 1993; Culik, 2010).

If the second option is included in the analysis, the value of the first option will change, because the value of its real product is no longer just the value of a real asset, since it is increased by the value of the second option. Since the value of the option cannot be negative at any time, the value of the basic product will either be the same or greater with the second option. If the first one is a call (put) option, its value will increase (decrease) with the second option. This means that the value of a growth option will increase if the second one is an option to abandon. It is easy to accept this: the second option can be seen as a kind of protection against future negative outcomes, so with all other factors unchanged, the decision-maker is more willing to call the growth option. As a result, the first option can only be priced if the second option is also taken into account.

Calling the first option may change the basic product and its value, which is at the same time the basic product of the second option. The result of this change may be that after calling the growth option it becomes less likely to call the second one, the option to abandon, that is, the value of the second option will fall. This shows that the second option cannot be priced without taking the first one into account.

Since both options influence each other, they must be priced simultaneously: the value of the first call option increases by that of the second, put option, but we need the put option to be able to price the call option, and vice versa. An extreme case of negative interaction occurs when the value of a portfolio is equal to the value of the most valuable, isolated option. Finally, it is also possible that there is no interaction at all between the examined options. If there are more than two options for the same basic product, the problem becomes even more complex, but the basic principles of interaction remain the same: the options must be priced simultaneously.

This is the same as a complex option, an option for another option, where the basic product of the first option is the second one. It is clear that this case calls for the options to be priced simultaneously: the contract price is the necessary pricing input, and the contract price here is equal to the unknown value of the second option. At the same time, the analogy between the features of real options described above and complex options is not clear because these real options are not only created by calling another option.

Correlation between options

Our goal is to determine a new market price that can be achieved by combining isolated projects, and the difference between this new market value and the old one is the extent of value creation. An isolated project and a real option are both priced as complex options in the option framework. Let us now take more than one project. If these projects are totally independent from one another, then the correlation between the project values is naturally irrelevant. However, if these projects are in any kind of interaction and are thus priced simultaneously, correlation becomes important. If several projects are assessed, several stochastic processes of the value of the given basic products should be modelled, including the correlation among them. The assessment should take into account how these processes change together; this is analogous to the pricing of standard financial options.

In general, the correlation may be constant or may change over time, depending on the calling of the real options. It is important to note that the correlation may be a kind of side-effect, and it is also possible that there is a real option the only goal of which is to influence the correlation. This is the case when by calling a real option the volatility of the

project value changes compared to the value of the basic product, so this option essentially helps to react to price movements. Double-fuel power plans are a typical example for this (Kulatilaka, 1993).

EMPIRICAL RESULTS

After providing a real options evaluation of the electrical energy generation technologies, detailed in Issue 4/2013 of the *Public Finance Quarterly* on an individual basis, I turned to the portfolio of real options and the effect of strategic value on the portfolio mix created by them. I attempted to find out whether the real options framework that makes it possible to adequately estimate the risk-yield characteristics of each generation technology proves to be an efficient decision-making tool for today's capacity planning experts.

The parameters I used for my calculations can be divided into two groups: factors derived from technology, and variables based on financial/economic estimates. Technological parameters: implementation time, useful life, capacity (load) factor, efficiency rate, size and capital cost. Financial-economic parameters: investment cost, fixed operating and maintenance costs, variable operating and maintenance costs, fuel costs and carbon costs. In my calculations, I relied on 13 databases (AEO, 2008; AEO, 2011; EERE, 2008; EIF, 2010; IEA, 2010; Minicam, 2008; NREL-SEAC, 2008; Oxera, 2011; POWER SWITCH, 2003; PB, 2011; Raeng, 2004; Risto T. – Aija K. 2008; Stretton S., 2010). These databases disclose information with varying levels of detail on technological, financial/economic parameters with varying units of measure, currencies and effective dates. As a consequence, the first step in performing my calculation involved finding a “common denominator” for these data, i.e.

I had to do the appropriate conversions and transposition to a common date using a 8 per cent risk-free rate based on the yield of a government bond with a maturity that is related to the average investment life expectancy. After that, with resulting data still showing significant variance, I calculated minimum, maximum and average values, then selected the data set to be used for each parameter, providing an appropriate explanation.

I performed the optimality analysis with Microsoft Excel™ Solver for the technologies that can potentially be included in the domestic electrical energy portfolio.⁵ When defining the limits, I used the statistical data (2011) published annually on the Hungarian Electrical Energy System (HEES) by Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zártkörűen Működő Részvénytársaság (hereinafter: Mavir Zrt.), according to which the domestic electrical energy production is 40 TWh per year.⁶

I defined the limits for the power production of each technology on the basis of the averages of their past data sets. According to the results of the programme run, 15 per cent of the cost-minimising portfolio come from coal, 28 per cent from natural gas, 38 per cent from nuclear energy and 20 per cent from onshore wind energy.

The results show that in addition to the coal, natural gas and nuclear technologies to be included in the portfolio on a fixed basis, onshore wind energy should also be included with its 8 million MWh generation capacity, which is not a realistic share given that wind energy is represented in the domestic electrical energy mix by 1.43 per cent with its current 534 thousand MWh generation capacity. According to the data of the Hungarian Wind Energy Association (2010) the average capacity of domestic onshore wind power plants is 2MW per unit. Taking an average load factor of 37 per cent on the basis of international

databases, this would require 6500 MWh of electrical energy per unit. The 8 million MWh of electricity can be generated by 1230 wind power plant units. Therefore, at this point I found it expedient to define another limit, this time for the technologies based on renewable sources.⁹

Realistic model limits determined on the basis of the unit size of renewable energy sources result in biomass and geothermal technologies gaining ground. Next, I found it expedient to run a model for the current domestic electrical energy mix in order to provide a comparison for the data, the energy mixes and the cost procedures that I received. (Formula 1)

As a further model specification, I defined the current weight ratio of the technologies

that are represented or can potentially be included in the mix as a lower limit and the capacity ratios calculated on the basis of the expansion possibilities proposed by Kádár (2010) as an upper limit. (Formula 2)

In my research, I carried out the volatility estimation for the various power plant investment projects using the MC simulation procedure, as it is the one most often used in sources, entails no aversion even among hands-on specialists, and – not in the least – is in synch with my methodological qualities. I used the Oracle Crystal Ball application to determine the probability distribution, average value and spread of selected uncertainty factors.

I approached the portfolio optimisation problem through the effect exerted by the op-

Formula 1

LIMITS OF THE MODEL

$\sum_{i=1}^{11} w_i \geq 0;$		$\sum_{i=1}^{11} w_i = 40\,000\,000 \text{ MWh}$	
$w_{\text{natural gas}} = 12\,000\,000 \text{ MWh};$	$w_{\text{nuclear}} = 16\,000\,000 \text{ MWh};$	$w_{\text{water}} = 200\,000 \text{ MWh};$	$w_{\text{biomass}} = 2\,100\,000 \text{ MWh};$
$w_{\text{wind}} = 600\,000 \text{ MWh};$		$w_{\text{coal}} = 6\,200\,000 \text{ MWh};$	
$w_{\text{oil}} = 500\,000 \text{ MWh}$			

Source: author's own editing

Formula 2

THE LOWER/UPPER LIMITS OF THE 3 MODELS⁸

$\sum_{i=1}^{10} w_i \geq 0;$		$\sum_{i=1}^{10} w_i = 100\%$	
$12\% \leq w_{\text{coal}} \leq 15\%;$	$2\% \leq w_{\text{crude oil}} \leq 5\%;$	$30\% \leq w_{\text{natural gas}} \leq 35\%;$	
$40\% \leq w_{\text{nuclear}} \leq 50\%;$	$4\% \leq w_{\text{biomass}} \leq 6\%;$	$4\% \leq w_{\text{wind}} \leq 12\%;$	
$0,5\% \leq w_{\text{solar1}} \leq 2\%;$	$0,5\% \leq w_{\text{geothermal}} \leq 5\%;$	$0,5\% \leq w_{\text{solar2}} \leq 2\%$	

Source: author's own editings

tion value, identified during option pricing, on the average geometrical yield of the projects and through the project value risk that reflects the joint effect of quantifiable uncertainty factors. My goal was to maximise an individual reward-to-variability ratio, that is the portfolio yields per unit of portfolio risk. (See Table 1)

Instead of combining the bi-nominal trees of each real option and identifying the qualitative and/or quantitative interactions between them, I approached the portfolio optimisation problem through the effect exerted by the option value, identified during option pricing, on the average geometrical yield of the projects and through the project value risk that reflects the joint effect of the three uncertain-

ty factors. First, I identified the average geometrical yields through annualising the ratio of the strategic value above the traditional net present value compared to the initial invested capital for useful life expectancy.

If in the first step I perform the optimisation in order to maximise the ratio of traditional internal rate of return (IRR) data compared to project value risk, the yield value for the entire electrical energy mix is 1.52 per unit risk, in which nuclear technology is represented by its maximum weight ratio on the basis of its risk-yield characteristics. The mix given by the programme run consists of 13.22 per cent of renewable energy and 86.78 of traditional electricity generation technologies. The optimisation procedure selects the tech-

Table 1

THE RISK-YIELD CHARACTERISTICS OF EACH TECHNOLOGY AGAINST STRATEGIC VALUE

	Initial situation			Real Option to Defer			Real Option to Expand		
	Yield ranking	Risk ranking	Yield ranking by risk	Yield ranking	Risk ranking	Yield ranking by risk	Yield ranking	Risk ranking	Yield ranking by risk
Coal	4	7	7	5	7	7	5	7	7
Crude oil	2	8	5	2	8	6	2	8	5
CCGT	1	9	2	1	9	2	1	9	2
Nuclear	6	1	1	7	1	1	7	1	1
Wind	6	2	4	6	2	3	6	2	4
Biomass	8	6	6	8	6	5	8	6	6
Natural gas CHP	4	10	8	3	10	8	4	10	8
Solar PV	9	5	10	9	5	10	9	5	10
Solar CSP	9	2	9	10	2	9	10	2	9
Geothermal	3	4	3	4	4	4	3	4	3

* Yield ranking: from highest to lowest; risk ranking: from lowest to highest; yield ranking per risk: from highest to lowest⁹

Source: author's own calculations

nologies with a rate of return characterised by high individual unit risk at a greater ratio than the lower limit, while the power plants with a low value are selected to the energy mix at the necessary minimum level (see *Chart 2*).

I carried out the optimisation procedure based on the yields increased by strategic value and the same limits, and as a result, the mix changed to a small extent only but the yield per risk unit was significantly different (growing to 1.92). The value identified by the real options to defer determined a kind of order for the inclusion in the mix. The strategic value resulting from deferment made some technologies more attractive, such as the natural gas-based technologies that have a higher weight in the mix as well as two renewable technologies, biomass and wind power plants. As a result, the mix changed (though only minimally) in favour of biomass and geothermal power plants (to an extent less than 1 per cent). The identification of strategic value definitely makes it possible to provide a more accurate estimation of project value and the quantification of managerial flexibility, not to mention the possibilities of reducing the risk of project value, not examined in this procedure, which entail an additional increase in the yields per risk unit.

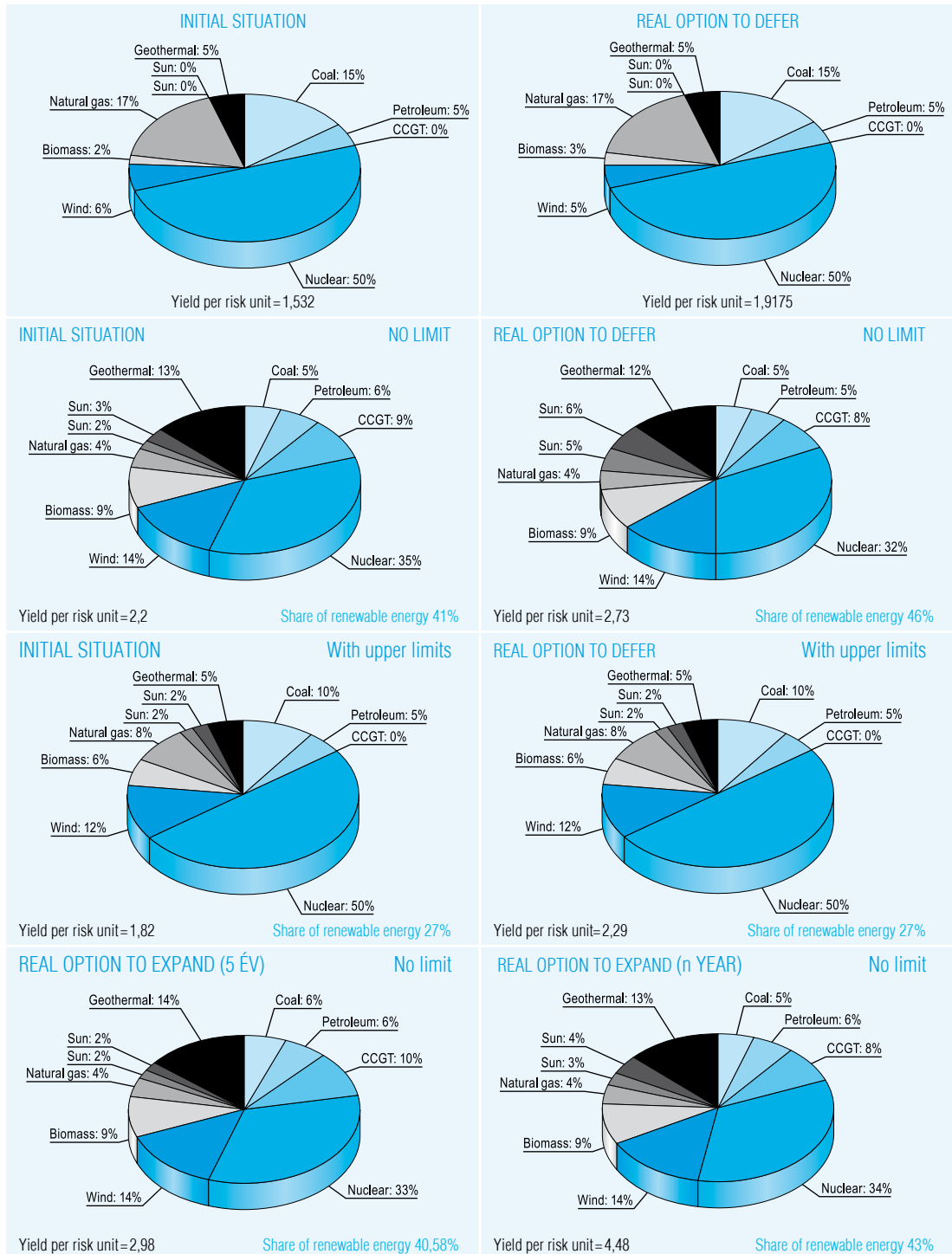
When I repeated these steps without the restrictive conditions, that is, without a prior orientation of the electrical energy mix, the mix changed significantly (see *Chart 2c*). The mix identified by internal rate of return data consists of 41 per cent of renewable technologies, and the yield of this mix per risk unit exceeds the value calculated on the basis of yields increased by strategic value in the case of the previous weights. In other words, the technologies with known risk and yield features suggest a mix consisting of 59 per cent of traditional technologies and 41 per cent of renewable technologies that can generate a higher yield for investors. If the option value

that can be realised by deferment is also taken into account, the mix changes significantly for the benefit of renewable energy generation (46 per cent), the winners of which are the currently extremely value-destroying solar technologies. In other words, a new generation of these technologies can become a dominant player (11 per cent) in the future time-of-day and peak service, thanks to the reduction of investment costs produced by the learning effect. The option value created by real options to defer gave the highest yield value (2.73) per risk unit in this case. It means that the real options analysis clearly verifies the value creation potential inherent in renewable energy sources.

Before I examined the effect of strategic value created by real options to expand on the mix, I determined the current mix of the Hungarian electrical energy system per limit, using initial IRR data, that is, annual yields without the value added component for the option value yields. As *Chart 3* shows, this mix gives the lowest yield value projected to the risk unit.

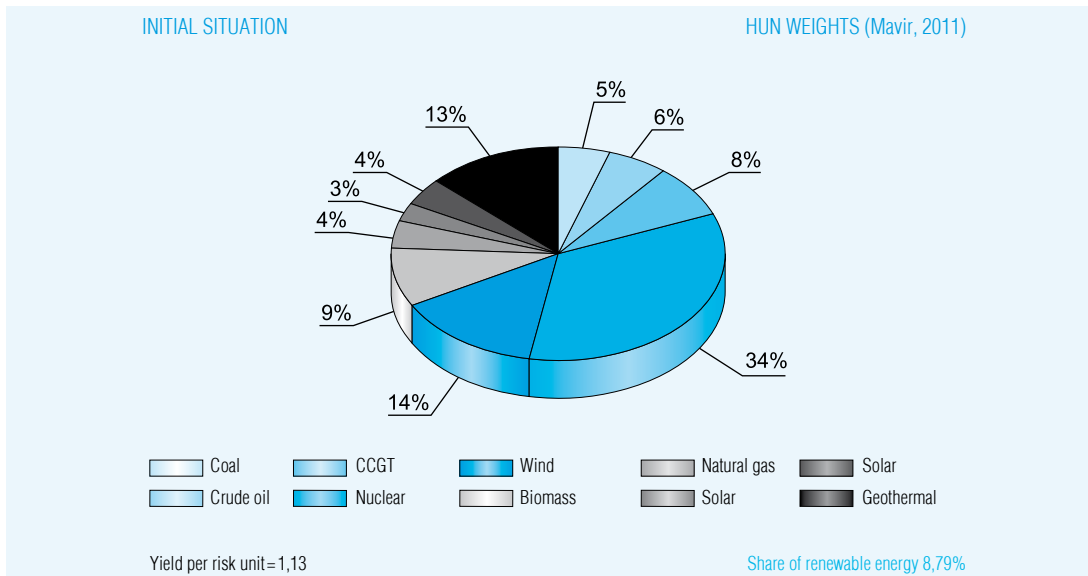
Compared to this, the highest reward-to-variability ratio so far is shown by the mix (2.98) which is created with taking into account the values of real options to expand without limits; this mix consists of 41 per cent of renewable technologies. All in all, the latter result and mix can be compared mainly with the mix created on the basis of the original IRR data calculated without limits. As noted above, this mix, which is characterised by a 2.2 yield per unit risk, consists of 41 per cent of renewable energies, which means that it is almost equal to the mix produced by taking into account the strategic value created by real options to expand, though its yield characteristics are different. All this reflects the experiences regarding the value created by real options to expand at the technological level and shows that the learning effect cannot be

THE EFFECT OF THE STRATEGIC VALUE CREATION OF REAL OPTIONS ON THE ELECTRICAL ENERGY MIX



Source: author's own calculations

RISK-YIELD CHARACTERISTICS OF THE CURRENT HUNGARIAN ELECTRICITY MIX



Source: author's own calculations

considered spectacular in the case of the real option to expand with a five-year maturity.

Much more remarkable is the mix which is the result of assuming the expansion of each technology at the end of their useful life expectancy and of the culmination of the learning effect; this mix, which has the highest yield per unit, 4.48 for its risk per unit in the study, consists of 43 per cent of renewable energies.

As a whole, I was able to examine the effect of the created strategic value on the electrical energy mix and on its profitability for two of the assumed three real options. In the case of real options to defer, when there are fixed limits (for the Hungarian mix), their ability to influence profitability is obvious; at the same time, renewable energy technologies, otherwise promising lower yield potential, can gain ground and have an impact on the mix in cases when there are no limits. The effect of strategic value on yields, created by real options to expand, may emerge primar-

ily in the short term, while the realignment of the mix as a result of the learning effect takes a longer time.

SUMMARY AND CONCLUSIONS

The characteristics of large, sometimes gigasized investments of complex engineering systems often require a multidisciplinary decision-making process. The investment parameters on which the decision-making is based, the optimality criteria underlying this process and the identification of the parameters of evaluation models also require mutual cooperation between engineering and economic professionals.

Both portfolio theory and real options theory characterise risk as a variance of yields stemming from assets. In portfolio theory, risk is minimised with a given yield or yield is maximised at the given risk level by combining assets with different risk features in the

diversified portfolio. Real options theory optimises the investments on the basis of future uncertain outcomes by taking into account managerial flexibility in decision-making. The real issue is not a “*top-down*” definition of the optimal mix, but the “*bottom-up*” understanding of the drivers of investor decisions that are confronted by both uncertainty and flexibility. All this will be the interest of regulators, who would like to understand how companies respond to uncertain market conditions or uncertain regulatory incentives.

The empirical results and qualitative arguments of this study are used to demonstrate that real options theory, along with portfolio

theory, can provide capacity planners with the most advanced optimisation tool for power generation mixes through taking advantage of the benefits of diversification and flexibility.

I believe that real options analysis is capable of putting the risk-yield characteristics of investment alternatives in complex technical systems to the service of energy mix identification, optimal from the environmental and profit perspective alike, by means of its meticulous project volatility estimation, the complexity of which will scare off many users, moreover through its option pricing process, supported by appropriate statistical and mathematical analysis software and IT.

NOTES

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² Contrary to some earlier papers in the literature (Childs et. al., 1998), in what follows I will assume that the projects are not mutually exclusive of one another (that is, every exploration and development project can be implemented).

³ The investment plan includes all the investments that a company intends to implement. Along with any other plans of the company, for example its financial plan, it represents the company’s comprehensive plan (Betge, 1995; Perridon – Steiner, 1997).

⁴ The lack of qualified staff is as limiting a factor as the lack of money.

⁵ I found it expedient to narrow down the range of 18 technologies in the entire research in order to

filter out the technologies that use the energy of tides, the energy provided by the waves of oceans and seas, which cannot be included in the domestic energy mix. On the other hand, I chose the alternatives from among the technologies using the same fuel, typically fossil fuel, which are present in the domestic energy mix and those technologies which are planned to be introduced by the domestic energy policy.

⁶ The domestic electricity consumption was close to 43 TWh in 2010, of which 5.2 TWh is imported electrical energy, that is, domestic gross power production does not reach 40 TWh, but I calculated with 40 TWh (Mavir, 2011), also taking into account the response of power plants to peak-period demand.

⁷ I used the size of units available in international databases as a limit.

⁸ When defining the limits for solar energy, I used the current (1 per cent) share and half of the potential (4 per cent) share for the power plants whose data are published in Mavir’s statistics (2011) in aggregate figures.

⁹ The most flexible power generation technologies are the coal-fuelled power plant technologies with the highest project value risk, followed by geothermal generation, then oil-fuelled power plants, wind energy and natural gas-fuelled power plants. The results of fossil technologies

are modified significantly if we include environmental uncertainty in the study. Project value volatilities reflecting the combined effect of the three uncertainty factors increase drastically, and thereby the parameters for binomial pricing are also modified.

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