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Power Generation Investment Timing in a Post Covid-Era

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ABSTRACT

This paper deals with the optimal timing of power generation investments in the second year of the global COVID-19 pandemic. The research applies the real options methodology during the investment decision-making process and takes, besides a proper uncertainty assessment, the project embedded flexibilities into account. Timing flexibility is discussed thoroughly, and the issue of optimal exercise, the timing of the highest potential value creation is examined through a static and dynamic lens. The authors' initial hypothesis presumed uncertainty as the most influential parameter measured by the project's standard deviation. Timing flexibility, optimal timing is analyzed compared to and concerning this volatility. Static and real options-based dynamic investment timing models are being tested in the power generation industry. Of particular interest of the research is whether results could prove the phenomena of renewable technologies being the safe haven of energy investments after the sector became highly volatile due to the COVID-19 pandemic. Results show that the timing of real options and the value will have a positive relationship. Still, the most exciting finding is that time and timing have a more substantial effect on the created value than uncertainty and further embedded growth potential (more flexibility).

Keywords: Real Options, Timing, Flexibility, Power Generation, Uncertainty
JEL Classifications: G11, C41

1. INTRODUCTION

One of the central premises of corporate economics is the decision-making process around real asset investments. Some aspects of explicit investor behavior are complicated to fit the conventional theorem. Most companies make their real asset investment decisions based on the future cash flows arising from the project being evaluated. According to the „time value of money" concept, proved already in the 16th century by Martin de Azpilcueta (1491-1568), the positive cash flows occurring closer to the present are more valuable than positive cash flows obtained in the distant future. This effect of timing of cash flows on investment policy and decision-making is more complex and significant than the concept itself. Timing affects the amount of funding required to make investments at different times in the future. All this impacts the particular investment and all the investments in the corporate project portfolio. In today's dynamically changing global economic and business environment, real asset investment has been exposed to many uncertainties. The uncertainty around the corporate projects requires the diligent work of managers, which includes determining the proper time of the investment. Without assessing uncertainty correctly, without an optimal real asset investment policy, and dealing with timing and its effect on the existing real asset portfolio and future investment opportunities, companies could end up underinvesting. Especially threatening is it in sectors with long research and development phases, long real asset life, mostly irreversible investments in a highly volatile flexibilities (opportunities) embedded environment (pharmaceutical industry, info-communication sector, energy sector). This paper chose to illustrate its real asset timing-related findings on power generation investments. The research focuses on investments timing, which includes the optimal start of investments. The paper deals in its next section with the current state and a quick outlook of the energy sector, then introduce the basics of static and dynamic real asset investment timing, finally applying them to the most significant types of power generation technologies in the Hungarian energy system.

After the initial shock of the pandemic, the lockdowns followed, entire economies, sectors shut down, then reopened, then shut down again; vaccination promised to be the light at the end of the tunnel. The global energy sector saw an unprecedented drop in energy demand while facing environmental issues becoming more highlighted, promoted, and in vogue than ever. Despite the accelerated start of vaccine rollouts, the ongoing economic stimulus, and fiscal responses worldwide, the emergence of new variants of the virus, and the size and effectiveness of the introduced measures, the sector has to deal with major uncertainties (IEA, 2021).

An optimal power generation investment policy is hard to develop, especially under the current, almost ambiguous circumstances. Optimality and optimal capacity expansion in the power generation sector are determined by factors based and building on each other. First, the reliable and secure supply of electricity, that drived investments, then cost minimization and profit maximization (value creation) came in. Nowadays, the mixture of the ability to capture strategic value, price-effectiveness, reliability, security, flexibility, environmental considerations, social acceptance, and existing capacities all drive the decision about the new capacity building.

2. LITERATURE REVIEW, METHODOLOGY AND DATA

By exploring uncertainty, a company may be able to reduce its risk exposure while at the same time creating value. Value creation can occur if a company finds a way to reduce the downside (adverse) risk while maintaining the upside effects (Billington and Kuper, 2000). More researchers have attempted to theoretically construct the risk taxonomy of the electricity market in recent decades, especially after its liberalization (Pilipovic, 2007; Weber, 2005; Burger et al., 2007), but none of these provides a complete picture of the possible uncertainties. From the investment point of view, the typology of uncertainty should be able to identify and separate the factors that most influence the optimal investment decisions. Botterud's (2003) short, and long-term uncertainty types show an appropriate approach, as these can be used to identify the main determinants of flexibility (option) value in addition to the factors driving the traditional value categories of electricity investments. The first-level of uncertainty factors are divided into three groups such as economic, technological, and regulatory or policy uncertainty (Table 1). Based on the results of Reedman et al. (2006), this paper deals with the effects of market uncertainty on the timing of investments. The market-based uncertainty arises from macroeconomic factors that cannot be controlled by the market participants (*fuel price, electricity market price, interest rate, exchange rate*). A significant portion of the produced electricity is generated by one of the primary energy sources *(coal, crude oil, natural gas, water, or uranium*). One of the most significant advantages of renewable energy over fossil fuel is that these are relatively unaffected by rising fossil fuel prices. However, renewable energy technologies cannot be considered risk-free either. Due to the unique physical properties of electricity, the wholesale price shows significant volatility compared to other exchange-traded products. Pilipovic (1998), for example, designates electricity as the commodity with the highest volatility risk, which is mainly caused by its storage properties.

The literature dealing with investment timing either uses the net present value maximization based static or the flexibility embedded dynamic approach. Variables used to explain, apply, and analyze the timing rules and models could be divided into technical and economic categories. Table 2 is summarizing these and introduces a notation used in the paper.

Table 1: Uncertainties in the power generation sector

Level of uncertainty			
Level 1	**Level 2**	**Level 3**	**Level 4**
Long-term uncertainty	Technological uncertainty	Technological uncertainty	Availability of technology
			Technology life expectancy
			Technological progress
			Social recognition of technology
	Economic uncertainty	Market uncertainty	Fuels price
			Electricity price
			Load change; demand
		Financial uncertainty	Liquidity
			Lending
			Exchange rate changes
			Interest rate
		Cost uncertainty	Investment costs
			Variable operating costs
			Fixed operating and maintenance costs
	Regulatory uncertainty	Legal uncertainty	Environmental standards
		Market structure	Liberalization measures
		Authorization uncertainty	Technology installation
Short-term uncertainty	Resource uncertainty	Operational uncertainty	Operational management
			Error, breakdown, shutdown
	Weather uncertainty	Extreme weather conditions	Extreme temperature and precipitation conditions
		Natural disasters	Hurricanes, floods, earthquakes

Source: Authors' own construction

The maximization of the net present value of a project is the basis of the static timing rules. Optimal timing occurs when a company can reach its investment goals while maximizing the value creation of a project under uncertain circumstances (Damodaran, 2002). Chu and Polzin (1997) defined three-timing rules. To receive optimal execution, they used the net present value maximization and the uncertainty of a project's annual net operating cash flows. The first rule is the traditional timing rule, where the decision maker's goal is only the value creation (NPV>0). In case of certainty, all the factors that determine the project's future cash flows are known. The goal of the decision-maker is to maximize the resulting net present value. Under uncertainty, the procedure is the same, maximizing, but the uncertain cash flow is based on net present value. All three rules are based on three parameters, namely the project value initial cost ratio (V/X), the annual net operating cash flows (B), and the project's life (t). The timing rules are summarized in Table 3.

The static rules provide information about the optimal timing of a real asset investment based on the critical values of C_T, C_U, C_C, B_T, B_C, B_U, T_T, T_C, T_U. The equations below define the critical values under the traditional, certain and uncertain circumstances.

Table 2: The variables used in this paper

Notation	Variable
B_C	annual net operating cash flow in case of certainty
B_T	annual net operating cash flow traditional case
B_U	annual net operating cash flow in case of uncertainty
C_C	the critical value of V/X in case of certainty
C_T	the critical value of V/X traditional case
C_U	the critical value of V/X in case of uncertainty
f	load factor (%)
F	fuel cost ($/MWh)
FC	fixed operating and maintenance cost ($/kW)
FCF	free cashflow ($)
m	annual project value growth rate (drift) (%)
n	project life (yr)
NPV	net present value $
P	the market price of electricity $/MWh
Q	plant output capacity MW
r	risk-free rate %
S	option underlying asset present value $
S*	trigger value of the underlying asset $
t	project exercise time (yr)
T	option life (yr)
u	immediate exercise, control variable
V	project value ($)
VC	variable operating costs ($/MWh)
X	initial investment cost ($/kW)
s	project value volatility (%)
t	optimal exercise time (yr)

Table 3: Static timing rules (R1-9)

Rule types	Rules and determinants					
	Project value initial cost ratio (V/X)		Annual net operating cash flows (B)		Project's life (t)	
Traditional	$V/X \geq C_T$	R1	$B \geq B_T$	R2	$t \geq T_T$	R3
Certainty	$V/X \geq C_C$	R4	$B \geq B_C$	R5	$t \geq T_C$	R6
Uncertainty	$V/X \geq C_U$	R7	$B \geq B_U$	R8	$t \geq T_U$	R9

Own construction based on Chu and Polzin (1997)

$$C_T = 1 \tag{1}$$

$$C_C = \frac{r}{r-m} \tag{2}$$

$$C_U = \frac{\beta}{\beta - 1} \tag{3}$$

$$\beta = 0,5 - \frac{m}{\sigma^2} + \sqrt{\left|\left(\frac{m}{\sigma^2} - 0,5\right)\right| + 2 \cdot \frac{r}{\sigma^2}} \tag{4}$$

$$B_T = (r-m) \cdot X \tag{5}$$

$$B_C = r \cdot X \tag{6}$$

$$B_U = C_U\,(r-m) \cdot X \tag{7}$$

$$T_T = ln\left|C_T \frac{X}{V(0)}\right| / m \tag{8}$$

$$T_C = ln\left|C_C \frac{X}{V(0)}\right| / m \tag{9}$$

$$T_U = ln\left|C_U \frac{X}{V(0)}\right| / m \tag{10}$$

While applying the above-detailed rules, it will be assumed that the investments analyzed are at least partly irreversible, and deferral is an opportunity until more information could be gathered about the cash flows. The net operating cash flows are time-dependent, their present value is known, and their future value follows a lognormal distribution with σ^2 as variance and *m* as an annual growth rate, where *m*>0 (both σ and *m* are fixed, known parameters). From a mathematical perspective, this results in the annual net operating cash flow following a geometric Brownian motion, which approach of uncertainty will allow a closed solution of the net present value maximization. Last but not least initial investment costs are known and fixed.

Based on the decision maker's investment goal (either reaching a positive net present value, a maximum net present value under certainty or a maximum net present value under uncertainty), these rules give valuable information about optimal investment timing. The first step of the process identifies the net present value (NPV):

$$NPV(t) = \left(V(t) - X\right) \cdot e^{-rt} \tag{11}$$

Where *r is the discount rate*, Based on the work of Dixit and Pindyck (1994), *V(t)* is the project value, while B(t) is the annual net operating cash flow from period t. The relation between them is the following assuming for maturity n:

$$V(t) = E\int_t^{\infty} B(n)\,e^{-r(n-t)}\,dn = \frac{B(t)}{r-m} \tag{12}$$

To further analyze the problem, it will be assumed that the discount rate is higher than the growth rate r>m, thus waiting would always result in a higher value. According to the traditional rule, the decision-maker will decide to start the project, regardless of the uncertainty, if the net present value reaches zero (*NPV(t)>0*), or in another form *V(t)>X. The immediate investment will be chosen if V(0)>X*, and waiting in case *V(0)<X. In the latter case waiting will have value since V(t) eventually will exceed the investment costs.*

The particular case, where the annual net operating cash flows are certain, their volatility will be zero, while their value in period t:

$$B(t)=B(0)\, e^{mt} \tag{13}$$

Where m is an annual growth rate of the annual net operating cash flows. In case equation (13) is substituted into equation (12), the project value in period t will be:

$$V(t)=V(0)\, e^{mt} \tag{14}$$

This will eventually result in a positive net present value even if today's present value of the future operating cash flows is below the initial costs of the investment V*(0)<X*. The main difference between the traditional and the certainty-based rule lies in the power of waiting since waiting will be more valuable in the latter, even if *V(0)>X*. The maximum of the net present value occurs () *V(0)-X*, when

$$V\left(0\right) > \frac{rX}{r-m} \tag{15}$$

Or

$$NPV_C^* = \frac{mX}{r-m}\left[\frac{\left(r-m\right)V(0)}{rX}\right]^{\frac{r}{m}} \tag{16}$$

The related R4-6 rules can be derived through maximizing the project value defined by equations (11) and (14) (the first-order condition $-[(r-m)V(t)-rX]\, e^{-rt}=0$). Till the project value of V(0) is only slightly above the initial cost of the investment (X), waiting will be the optimal decision.

The stochastic framework is introduced into the analysis in the R7-9 uncertainty rules, where it is assumed that the annual net operating cash flows follow a stochastic distribution. In this case, it is impossible to determine the optimal timing of the investment through the net present value maximization process. The solution will be identifying a critical project value, which could result in an optimal project implementation date. Dynamic programming, and with the application of the contingent claim valuation, Dixit and Pindyck (1994) proved that the optimal timing occurs in case the project value reaches the critical value of V*:

$$V^* = \frac{\beta}{\beta-1}X \tag{17}$$

Where Dixit and Pindyck (1994) defined while solving dS Bellman equation for beta under the conditions of *V(0)=0; V(S*,t*)=S*-X and* $V_S(S^*)=1$ as:

$$\beta = 0,5-\frac{m}{\sigma^2}+\sqrt{\left|\frac{m}{\sigma^2}-0,5\right|+2\frac{r}{\sigma^2}} \tag{18}$$

The R7 timing rule will be only valid according to that, if $\frac{V(t)}{X} \geq \frac{\beta}{\beta-1}$. R8 can be derived from R7 while assuming the relationship between the net operating cash flow and the project value described in equation (12). Instead of finding an exact optimal implementation period, rule 9 (R9), the optimal timing connected to the critical value, will be only an expected optimal implementation period. As Martzoukos and Templitz-Sembitzky (1992) highlighted, the expected optimal project implementation period is:

$$T_U = \frac{1}{m} ln\left[\frac{\beta}{\beta-1}\cdot\frac{X}{V(0)}\right] \tag{19}$$

The maximum expected net present value of the project:

$$NPV_U^* = (V^*-X)\left[\frac{V(0)}{V^*}\right]^{\beta} \tag{20}$$

The company's operational efficiency and optimal execution of investments can be increased by applying the real options theory. McDonald and Siegel (1986), Dixit and Pindyck (1994) built up a one-option model, in which they assumed that reinvestment could not take place in the future and only a particular option could be exercised. In optimal investment timing, the project's annual operating cash flows and investment cost can be considered continuous over time and follow stochastic processes (irreversible projects). In their timing research, they handle the investment opportunity as an American option.

Similar to Dixit and Pindyck (1994), McDonald and Siegel (1986), Sarkar (2000) takes the real options theory as a basis of his model. Still, instead of the firm value, his study determines annual operating cash flow following lognormal distribution as a state variable, and it explicitly considers systematic risk. Chang and Chen (2011) used Sarkar's model, creating a real options model in which the cash flows follow geometric Brownian motion and mean-reverting process. The increase of uncertainty leads to the rise of investment probability and positively affects the investments.

Luehrman (1998) developed one of the best-known models of the literature of real asset investment timing from a strategic perspective. He regarded the corporate strategy as a series of options rather than a set of static cash flows, thus emphasizing real options. His model is built on a tomato garden analogy that describes its circumstances and the opportunities embedded in the garden. According to his argument, the „now or never" decision made at a deficient level of uncertainty, execution of investment, and exercise of real options is immediately worthwhile. As the level of uncertainty increases, deferral may become valuable. He also further divided the decision space and differentiated real options according to their intrinsic values. Projects with positive intrinsic value and low uncertainty should be exercised immediately. In contrast, real options with negative intrinsic value, which have low volatility, should be rejected but with a high level of uncertainty; future implementation and the possibility of exercising real options should be maintained.

From theory to practice, an American type of option needs to be assessed. By the analogy of the net present value-maximization, now an option value is being maximized, which occurs if τ(the optimal time to exercise) maximizes

$$\mathbb{E}_x\left[\left(S_\tau e^{-r\tau}-X\right)\right] \quad (21)$$

the intrinsic value. The equation tries to find the optimal investment implementation period, which is determined by S state variable and the initial investment cost of X, where r is the discount rate, while τ is the optimal exercise date (from now on, the notation changes to the option terminology, where S is the underlying asset's value in period t, and denoted with S_t *and S* will be the underlying asset value connected to the optimal timing. If S follows a geometric Brownian motion, the model will either result in an immediate implementation or a project delay.* At this point, let's turn back to the fundamental question of the research: When strictly should the investment be implemented? Whether a product launch, geographic expansion, acquisition, etc.; these projects are considered all as call options. When is it worth exercising an American-type of real options? Barone-Adesi and Whaley (1987) proposed an approximation solution for American-type financial options. The approximation method gives an entirely new dimension to applying real options by supporting strategic decision-making with assumptions close to real life. At the same time, it is essential to emphasize that the optimal timing for this method is only a spinoff of approximation. For the value of the project S, while its exercise price X will be assumed. Abstracted from the infinite maturity, a time limit allows the investor to invest X amount of capital until period T. Thus the opportunity open to exercise the option (τ). τ is smaller than T in all cases, i.e. the investing company can decide to start immediately or postpone the project to obtain further information about the evolution of S. Let u be a control variable of decision-making about exercise or deferral (1 or 0 respectively). The value of an investment with timing flexibility:

$$V(S,0)=max_u\{S(0)-X;\mathbb{E}_0\left[\left(S_\tau e^{-r\tau}-X\right)\right]\} \quad (22)$$

where (S-x) is V(S,τ), i.e. the formula can be simplified as follows:

$$V(S,0)=max_u\{S(0)-X;\mathbb{E}_0\left[V(S,\tau)e^{-r\tau}\right]\} \quad (23)$$

Today's project value will be the maximum of the expected present value of the project started in period τ and in period τ=0. This maximization is driven by the control variable u, which represents the companies decision about the project. Equation (23) shows that the project value *(V)* will be consistently above zero, although it is not providing any insight about the optimal timing of the project. To get closer to the desired trigger value and corresponding trigger period, equation 23 is considered a dynamic programming task, a Bellman equation. (Simonovits, 2003), where the *u=1* control variable setting, the project value will be the sum of the premium received while exercising and the utility of the upcoming state (see equation (24)).

$$V(S,\tau)=max_u\{S(\tau)-X;\mathbb{E}_\tau\left[V(S+\Delta S,\tau+\Delta\tau)e^{-r\Delta\tau}\right]\} \quad (24)$$

This dynamic programming problem can be approached with a backward solution starting from the final time (T) available to implement the investment. It is the maximization problem for control variable u. The problem can be solved after gathering information about the project value (S). As noted earlier, the geometric Brown motion of the cash flows and thus the project value can be assumed. If the change of project value (S) over a unit time (drift) is m and the variance is *s, then*

$$dS=mSd\tau+\sigma Sdz \quad (25)$$

where dz is a Wiener process. Writing Equation (24) with this in continuous time:

$$V(S,\tau)=max_u\{S(\tau)-X;\mathbb{E}_\tau\left[V(S+dS,\tau+d\tau)e^{-rd\tau}\right]\} \quad (26)$$

Concerning the analyzed problem, both the percentage change of project value per unit time (m), and volatility (σ) are time and state-dependent, the equation (26) can be rewritten by substituting Ito-lemma[1] (a) as follows:

$$(1-rd\tau)\left[V(S,\tau)\right]+V_\tau(S,\tau)d\tau+V_S(S,\tau)mSd\tau+\frac{1}{2}V_{SS}\sigma^2S^2d\tau \quad (27)$$

Substituting this relation into equation (26), formulating the maximization conditions, it can be concluded that

$$\frac{1}{2}V_{SS}(S,\tau)\sigma^2S^2+V_S(S,\tau)mS+V_\tau(S,\tau)-rV(S,\tau)=0 \quad (28)$$

where the conditons are: *V(0)=0; V(S*,t*)=S*-X and* $V_S(S^*)=1$.

At a specific time in the future, the exercise of the option (deciding to start the project) can be optimal when u=1. These conditions were already formulated by Dixit - Pindyck (1994) and Merton (1973). Those mentioned above created the condition of „value-matching", while the latter the condition of „high contact," which is one of the primary conditions for time to expiration optimization.

If an optimal S* value exists, it must be independent of the project's present value. As long as the S present value reaches the S*, the value of current implementation and the value of waiting are the same, i.e., there is no additional advantage to wait. To find the (time) point before T where it is worth calling the option, it is necessary to change the restrictive conditions.

As a first step, the project cannot be implemented before time T, i.e.:

$$V(S,T)=\max(S(t)-X;0) \quad (29)$$

This will be the new constraint of equation (28). Ingersoll (1987) obtained the following equation after substituting the expectation transformation and S as a solution in (25) differential equation:

1 If the V project value is the function of S and t, according to Ito-lemma, V has to follow the following process:

$$dV=\left(\frac{\partial V}{\partial S}mS+\frac{\partial V}{\partial\tau}+\frac{1}{2}\sigma^2S^2\frac{\partial^2V}{\partial S^2}\right)d\tau+\frac{\partial V}{\partial S}\sigma Sdz\} \quad \text{(a)}$$

$$V(S,\tau)=e^{(m-r)(T-\tau)}SN(d_1)-Xe^{-r(T-\tau)}N(d_2) \quad (30)$$

where

$$d_1=\frac{ln\frac{S}{X}+(m+0,5\sigma)(T-\tau)}{\sigma\sqrt{T-\tau}} \text{ és } d_2=d_1-\sigma\sqrt{T-\tau} \quad (31\text{-}32)$$

The following step is to map the relationship between the *m* growth rate and *r* discount rate. The Financial option theory solves this problem by adjusting the growth rate to the appropriate level of risk and then discounting it with a risk-free rate. All this is derived by Merton (1973) assuming a non-arbitrage situation, while Black and Scholes (1973) deduce it from an equilibrium model.

The solution to equation (28) cannot be found if the real option can be exercised at any time with this constraint; however, the practice requires it. Barone-Adesi and Whaley (1987) proposed an approximation solution for American-type financial options. Based on the analogy between financial and real options, this is used to determine the value of the expectation. Additional conditions for approximation: Let $M=\frac{2r}{\sigma^2}$; $N=\frac{2m}{\sigma^2}$ and *t=T-t,* as the remaining time to call. Under these conditions, the approximate solution of equation (28):

$$V(S,\tau)=v(S,\tau)+A_2\left(\frac{S}{S^*}\right)^{q_2} \text{ if } S<S^*;\ V(S,\tau)=S-X \text{ if } S\geq S^* \quad (33)$$

$$A_2=\{1-e^{(m-r)\tau}N\left[d_1\left(S^*\right)\right]\}\frac{S^*}{q_2} \quad (34)$$

$$q_2=0,5[-(N-1)+\sqrt{(N-1)^2\frac{4M}{N}} \quad (35)$$

*S** implicit solution of the following equation:

$$S^*-X=v\left(S^*,\tau\right)+\frac{\left\{1-e^{(m-r)\tau}N\left[d_1\left(S^*\right)\right]\right\}S^*}{q_2} \quad (36)$$

where v(S,τ)

$$v(S,\tau)=e^{(m-r)\tau}SN(d_1)-e^{(-r\tau)}XN(d_2) \quad (37)$$

where d_1 and d_2 parameters are:

$$d_1=\frac{ln\frac{S}{X}+(m+0,5\sigma)\tau}{\sigma\sqrt{\tau}} \text{ és } d_2=d_1-\sigma\sqrt{\tau} \quad (38\text{-}39)$$

3. RESULTS

In this section five, power generation technologies (nuclear power, onshore wind, biomass plants, photovoltaic plants, and geothermal plants), that are to be installed or potentially extended in the Hungarian energy system will be analyzed with the real option methodology focusing on the dynamic timing optimization of the chosen real option types. Other potentially smaller capacity technologies will be excluded from the analysis to make each technology comparable. In the research, a hypothetical 3.6 TWh electricity consumption is assumed, and fitted to this, a rational number of units were considered regarding the chosen technologies (small scale technologies were excluded). Based on the average unit size, more than 230 units of photovoltaics would be needed to produce the amount of power that is doable from a single average unit of coal powered plant, which would sufficiently provide the power needed to the assumed power consumption. Regarding the electricity supply security, it was evident that a system based on one single technology is only viable if only traditional technologies are involved; from the renewable technologies, only the geothermal and biomass technology-based system would be rational. In the case of the geographical and weather risk-stricken wind and photovoltaic technologies, only an irrational capacity extension could fulfill the large power demand, not to mention the price and amount of value destruction.

Before the previously introduced static and dynamic approaches of investment timing, variables need to be identified and valued, while some assumptions need to be declared. The latter two assumptions were used in the research, one regarding the annual risk-free rate (r), and one regarding the average annual growth rate of cash flows (m). Calculated variables were: the real options underlying asset's present value (V), which was calculated as the sum of the present value of the free cash-flows (FCF) (Takács, 2009). The following equation shows the detailed steps of reaching V, where Q is the output produced altered by the load factor (f) while P is the market price. The load factor is the measure linked to a theoretical maximum output capacity. It can be defined as the ratio of the output produced by a plant in a certain period and the theoretical maximum that it could have produced (Lopez and Salies, 2006)[2]; FC is the technology's fixed cost, while the load factor again alters variable cost (VC); F is the fuel cost; 8760 working hours were assumed (24 h 365 days). Project value volatility was assessed based on Copeland és Antikarov (2002) by the Monte Carlo simulation of the project's net present value (flexibility/option value excluded).

$$FCF=\sum_{t-1}^{n}8760\cdot f\cdot Q\cdot P-FC\cdot 1000\cdot Q$$
$$-VC\cdot 8760\cdot f\cdot Q-F\cdot 8760\cdot f\cdot Q \quad (40)$$

$$V=\sum_{t-1}^{n}\frac{FCF_n}{(1+r)^n} \quad (41)$$

Calculations are based on data gathered from databases behind the Annual Energy Outlooks of the U.S Energy Information Administration (EIA), of the International Energy Agency (IEA), of the Energy Efficiency and Renewable Energy (EERE), of Oxera, of the National Renewable Energy Laboratory (NREL) from the years 2010 to 2020. These databases disclose information with varying levels of detail on technological, financial/economic parameters with varying units of measure, currencies and effective

2 José López and Evens Salies, 2006. „Does vertical integration have an effect on load factors ? – A test on coal-fired plants in England & Wales, Sciences Po publications 2006-3, Sciences Po.<https://ideas.repec.org/p/spo-/wpmain/infohdl2441-7069.html>

dates. As a consequence, the first step was involved finding a „common denominator" for these data, i.e., an appropriate conversion and transposition to a common date.

From the three static investment timing rules, the traditional rule's results are worthy to analyze, where the goal is to reach a positive net present value, the point of value creation. The project value divided by the initial cost of the plant (V/X) needs to reach the value of 1 according to Rule1 (R1), which is in line with the rule of thumb of the profitability index. The V/X ratios result exceeds the critical value in the case of every involved technology, except for the photovoltaic power generation, where the initial costs are too significant to be covered. Based on their results and on the value introduced with equation (12), the traditional timing-based decision would suggest an immediate implementation of four of the technologies, while in the case of photovoltaics, waiting would create more value.

The second rule (R2) uses the annual net operating cash flow values (B), which also exceed related to every involved technology the critical value suggested by equation (5) (Table 4). Since $B \geq B_T$ it enforces an immediate implementation.

Time is the third parameter of the static timing model, which is a proxy of the decision-makers optimal timing of the implementation. The critical value (T_T) is identifiable through equation (8), where C_T critical value is 1. As shown in Table 4. in the case of the PV technology, in 15.5 years is optimal to invest, while the other technologies produce an immediate start's 0 value. Summarized, the PV technology from the renewables suffers from the burden of a high initial cost, which is the core variable of the static timing models. The static result's reality is questionable; one should concentrate on the relation and ranking of the technologies instead of the actual values. Based on the value

Table 4: Static investment timing of the chosen technologies

	Nuclear	Onshore wind	Biomass	PV	Geothermal
V (0) m$	5686.0	4987.0	4149.0	4058.0	4291.0
X m$	2715.0	1837.0	1877.0	6457.0	776.0
X/V (0)	0.5	0.4	0.5	1.6	0.2
V/X	2.1	2.7	2.2	0.6	5.5
B m$	639.0	392.0	297.0	288.0	331.0
B_T m$	54.3	36.7	37.5	129.1	15.5
B_C m$	81.5	55.1	56.3	193.7	23.3
B_U m$	141.8	120.4	125.4	454.9	53.7
C_T	1.0	1.0	1.0	1.0	1.0
C_C	1.5	1.5	1.5	1.5	1.5
C_U	2.6	3.3	3.3	3.5	3.5
T_T yr	0	0	0	15.5	0
T_C yr	0	0	0	29.0	0
T_U yr	7.3	6.3	13.8	57.5	0
r	0.030	0.030	0.030	0.030	0.030
m	0.010	0.010	0.010	0.010	0.010
s	0.180	0.280	0.290	0.320	0.310
b	1.621	1.439	1.427	1.396	1.406

Source: Own calculations and construction based on the data provided by the U.S. Department of Energy (2015); EIA (2010; 2012; 2013a; 2013b; 2013c; 2014a; 2014b; 2015a; 2015b; 2015c; 2016a; 2016b; 2016c; 2017a; 2017b; 2017c; 2018a; 2019; 2020; 2021); IEA (2010a; 2010b; 2011a; 2012a; 2012b; 2013a; 2013b; 2014a; 2014b; 2015; 2016; 2017; 2018; 2019; 2021)

creation potential, the power generation portfolios should move in favor of the renewable technologies, which shift could be the result of the learning effect of these.

The dynamic investment timing approach builds on the optimal value of each technology, which could be considered a maximum value, a trigger value (the sum of the traditional value creation and the strategic value of flexibility). Because of the complexity of this search for the trigger value-based optimal timing process, the range of the examined technologies was narrowed down to one traditional power generation technology (nuclear) and to one renewable technology (onshore wind). Nuclear, in line with the Hungarian plan of PAKS II. (new nuclear plant), with which the state intends to maintain the share of nuclear energy in domestic electricity production in the long run. Wind, since Solar PV and wind are expected to contribute two-thirds of renewables' growth in 2021 (IEA, 2021). The dynamic investment timing approach builds on the optimal value of each technology, which could be considered a maximum value, a trigger value (the sum of the traditional value creation and the strategic value of flexibility). Because of the complexity of this research for the trigger value-based optimal timing process, the range of the examined technologies was narrowed down to one traditional power generation technology (nuclear) and to one renewable technology (onshore wind).

Based on the already introduced and during the static process used variables, the optimal project value, the trigger value (S*) was calculated while analyzing the effect of influencing parameters. Trigger value reached, the project reaches the optimal time of start. The research assumes a two-year timeframe and examines the 3, 6, 9, 12, 18, 24-month trigger values related to different growth rate and volatility assumptions. As Tables 5-7 shows, the real option's exercise date is in close relation to the project's trigger (suggested optimal) value. As far as the available time to exercise is shrinking (from 24 months down to 3 months time), the value needed to trigger action also shrinks. Table 5 lists the trigger values that would result in an immediate implementation in the exercise date listed in column 1. The effect of timing flexibility is higher in the case of renewable technology. The incremental value (percentage increase in the trigger value) starts to decrease immediately, reaching a slightly higher value at the point of a start in 1.5 years (109.5%), while reaching a significantly higher value creation in case of the onshore wind technology (116%). The effect of the cash-flow growth (m) was also examined, and as Table 5 shows, it has a more significant effect on the trigger value in the renewables technology, but lower than the effect of time.

With Tables 6 and 7, the effect of volatility was built into the research. In these runnings, both time and project volatility is analyzed ceteris paribus. As Table 6 shows nuclear technology, the effect of timing on the trigger value is higher at every level of volatility than the volatility increase's effect on the incremental trigger value. The trigger value increases with volatility but decreases (logistic growth), and this is true regarding timing. This phenomenon is interesting because time and optimal timing have a more significant effect on value creation than volatility. The decreasing incremental value suggests the advantages of

Table 5: The effect of timing and growth rate (1 and 2%) on the trigger value S* in the case of the nuclear and the onshore wind technology ($S_0^{nuclear} = 2715; S_0^{wind} = 1837;$ Values in m$)

Nuclear technology					Onshore wind				
t (month)/m%	0.01	∆	0.02	∆	t	0.01	∆	0.02	∆
3	3 295		3 324		3	2482		2533	
6	3 570	108.3%	3 620	108.9%	6	2823	113.7%	2939	116.0%
9	3 801	106.5%	3 877	107.1%	9	3125	110.7%	3320	113.0%
12	4 011	105.5%	4 116	106.2%	12	3408	109.1%	3695	111.3%
18	4 393	109.5%	4 565	110.9%	18	3952	116.0%	4460	120.7%
24	4 747	108.1%	4 996	109.4%	24	4486	113.5%	5265	118.0%

Own construction, own calculation

Table 6: The effect of time and volatility on the trigger value S* of the nuclear technology, where values are in m$, ∆ σ is the effect of volatility and ∆ τ is the effect of timing

s(%)/t (month)	3	∆σ	6	∆σ	9	∆σ	12	∆σ	∆τ	∆τ	∆τ
16	3198	0	3421	0	3607	0	3775	0	107.0%	105.4%	104.7%
18	3295	103.0%	3570	104.4%	3801	105.4%	4011	106.3%	108.3%	106.5%	105.5%
20	3363	102.1%	3675	102.9%	3939	103.6%	4179	104.2%	109.3%	107.2%	106.1%

Own construction, own calculation

Table 7: The effect of time and volatility on the trigger value S* of the onshore wind technology, where values are in m$, ∆ σ is the effect of volatility and ∆ τ timing

s(%)/t (month)	3	∆σ	6	∆σ	9	∆σ	12	∆s	∆τ	∆τ	∆τ
26	2428	0	2734	0	3001	0	3250	0	112.6%	109.8%	108.3%
28	2482	102.2%	2823	103.3%	3125	104.1%	3408	104.9%	113.7%	110.7%	109.1%
30	2539	102.3%	2919	103.4%	3258	104.3%	3580	105.0%	115.0%	111.6%	109.9%

Own construction, own calculation

waiting melting away at a certain level of volatility. In contrast, the advantage of a more volatile environment seems less than expected in the case of nuclear power generation technology.

In the case of renewables, an interesting finding is that the effect of volatility increase is almost zero. At the same time, timing has a significant effect on the trigger value, which is larger than the above analyzed nuclear results.

This effect is highlighted in Figure 1., which also proves the more significant effect of time on the value creation potential of the technologies in nuclear technologies.

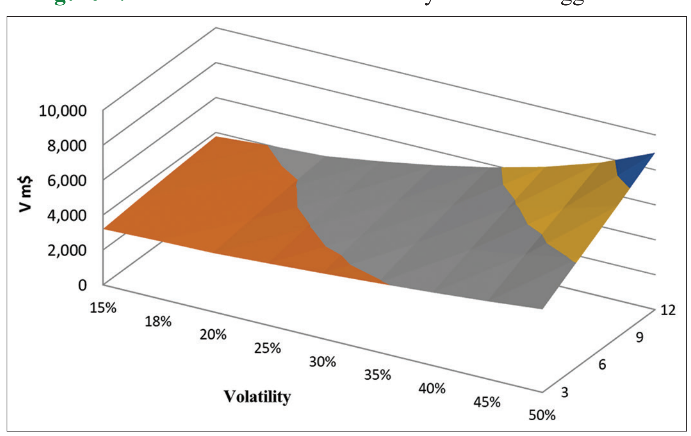
In both technologies, the effect of volatility varies between +2 és +6%, where the more significant incremental changes occur at deferred implementation dates—compared the effect of time varies between +4% and +15%. This would mean that in nuclear technology, to reach the effect of time on the trigger value, one would have to assume the volatility to double, while related to the renewable technology, the value could not be reached at a rational volatility level. Instead of focusing on most managerial decisions, volatility seems to be less attractive than timing, or at least time; timing is as crucial as volatility.

The decision-makers who receive a trigger value close to the result of the traditional valuation (S_0) as project value should not wait to implement the project because it is not worth it. Still, those with a significantly higher trigger value with the embedded flexibility should consider waiting. Table 8. summarizes the effect of time on the timing flexibility increased project value V(S; τ). It was already proved in the option theory literature, the increase in time increases the value of the option, in this case, the value of the power

Table 8: The effect of the change in time on the real option value (in m$)

t (month)	Nuclear	Onshore wind
3	579	656
6	849	992
9	1075	1289
12	1278	1566
18	1645	2093
24	1980	2605

Figure 1: The effect of time and volatility on the S* trigger value



Own construction, own calculation

generation plants. This research aimed to prove and concede more than that, namely that the effect of timing will be more significant than the effect of change in the growth rate or in volatility.

4. CONCLUSION

In this research investment, timing models were applied and analyzed regarding power generation technologies. The study aimed to examine the effect of time and volatility in the post-pandemic, highly volatile investment environment. Since exclusivity is usually granted in the power generation sector, the timing flexibility is appropriate to be considered without risking losing the first-mover advantage. The paper started with a detailed introduction of uncertainty sources that affect project volatility in the power generation sector, then introduced the methodology applied, namely static and dynamic investment timing models.

The research was narrowed down to five power generation technologies. Investors consider renewable technologies a safe-haven of investments these days, which could be proved and approved while applying static and dynamic timing models. Renewables seem to be still riskier at first, bringing in less money and a higher payback period. Still, the models gave lower optimal implementation dates than they would have a decade ago through the learning effect. Traditional technologies still create more value assuming the same capacity and maturity. Still, the gap between traditional and renewables is shrinking, and as the results have shown, if embedded flexibility is taken into account, it even disappears (Table 8). Regarding the timing research's results, static models give insight into the relation and ranking of the technologies, while dynamic models suggest optimal trigger values and exercise time. Not only has it proved to be potentially more worthy after taking flexibility into account, but it seems to be unaffected by volatility growth. The decision-makers who receive a trigger value close to the result of the traditional valuation (S_0) as project value should not wait to implement the project because it is not worth it. Still, those with a significantly higher trigger value with the embedded flexibility should at least consider waiting.

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