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THE APPLICATION OF SIMULATION METHODS AS A TOOL FOR THE CONSTRUCTION OF EXPERT LONG-TERM FORECASTS

Summary: The application of simulation methods allows for the consideration of the influence of key events in the case of determining long-term forecasts. The influence of events upon the base values of different nature, strength of the influence, frequency of their occurrence or the time of occurrence may be difficult in the case of constructing a classic model. The simulation approach allows not only for the determination of the total influence but also for the consideration of particular cases and the performance of a wide range of diagnostic tests that verify the strength of influence of the adopted hypotheses. The accepted methodology of determining the forecasts may be applied not only in the foresight research. In reality it was originally created for such a research and here it may find the broadest application.

Key words: foresight, key events, simulation methods.

1. Introduction

The issue discussed in the article is related to a foresight research included in a broader project entitled: “Zero-emission economy of energy in the condition of balanced development of Poland up to 2010”. The article presents one of the stages of the research that consists in the determination of future directions of development for selected zero-emission technologies with the consideration of the influence of various factors. The full characteristics of the considered problem as a whole was defined in the study [Gajda 2011]. The study [Poradowska 2011] presents the methodology of defining basis curves that are the initial value for which, in this article, key events determining its future character will be determined. The basis curves (in the next part also called the basis values) are forecasts for the amount of production of energy derived from various sources. At this stage of the research for these sources the occurrence of the key events that are defined may have a fundamental influence on the forecast values. The key events were defined as rare events whose. impact on the basis value in case of their occurrence may be substantial (this problem is discussed more extensively in [Wójciak 2011]). The events themselves may be an effect of sudden political, technological changes; they can also belong to random events independent of human influence, such as volcanic eruptions, catastrophic floods or earthquakes. The purpose of this article is to present the methodology of aggregating the experts' data when determining the scenarios of development of zero-emission economy in the perspective of 2050, in the case when all the values that describe the given problems are achieved on the basis of expert opinions from various fields of science. The consideration of all possible key events that come from different sources and thus have a diversified influence upon the basis value is so complex that the construction of a formal model in such a case is significantly hampered and one of the possible solutions is to apply simulation methods. The later part of the article describes, as follows: the role of experts in the research and the values which they had to define for the purpose of the simulation task, simulation procedure as a tool to correct the forecast on the basis of a hypothetic problem, the analysis of results and the possibilities of applying simulation as a tool for the construction of forecasts.

2. The role of experts in the research

The initial value in this part of the research, as is mentioned in the introduction, is the basis value defined individually for each of technologies listed by experts. For a considered technology, experts determine a set of key events together with their parametric description according to an adopted scheme. The parametric description of each individual event increases the elasticity of research. The maximum and minimum limits are not assumed for the considered number of events. The experts who define key events determine how long a given event may last, what an expected power and the character of influence it will have in different sub-periods. The parametric description dependent on the experts can be divided into three stages:

– determination of the chances for an event to occur in the distinguished sub-periods,
– determination of the time the event lasts and the power of its influence,
– determination of the character of influence in sub-periods and the recurrence of events in 2011-2050.

The first stage is to determine the chance for a given event to occur. The horizon of the forecast, i.e. 2011-2050, was divided into 4 decades. For each of the four sub-periods the experts define chances of occurrences that are expressed in percentages as values from interval 0; 100%].

In the second part the experts define the period and the power of influence of a given key event in the distinguished sub-periods. In this case the initial moment is a hypothetic moment of occurrence, unrelated, at this stage, to individual years of the period 2011-2050. Time in particular sub-periods is calculated from the time of occurrence, marked by M_0 to moment M_3 as the moment of reaching the terminal level. These values are given by experts in years. With regard to a possible various character of development of a given event, two moments that take place in the period from M_0 to moment M_3 are defined. The following moments are distinguished:

M_0 − time up to the occurrence of the first effect,

M_2 − time till the end of the influence of a direct event.

Each moment is related to a percentage influence, with the exception of moment M_1 for which the value of influence is defined as zero, which means that the basis value is adopted. At this stage it is possible to modify the methodology assuming that the occurrence of event results in an immediate percentage influence in period M_1. The strength of the influence itself may be defined by positive and negative values. There is also no limitation as it comes to the mutual direction of changes for periods M_2 and M_3, i.e. after a negative influence (possible decrease of basis value as a result of the event occurrence) there may be a positive influence (possible increase of basis value), or the other way round. An exemplary effect of influence is presented in Figure 1, where axis OX defines time and axis OY is the axis of percentage influence of a given event *Z1* upon the basis value. The scale of axis OY in this case begins with the value of 1; while all the values given by the experts are deviations from the basis value and, e.g. the moment M_2 defined in the research as +50% equals 1.5 on axis OY.

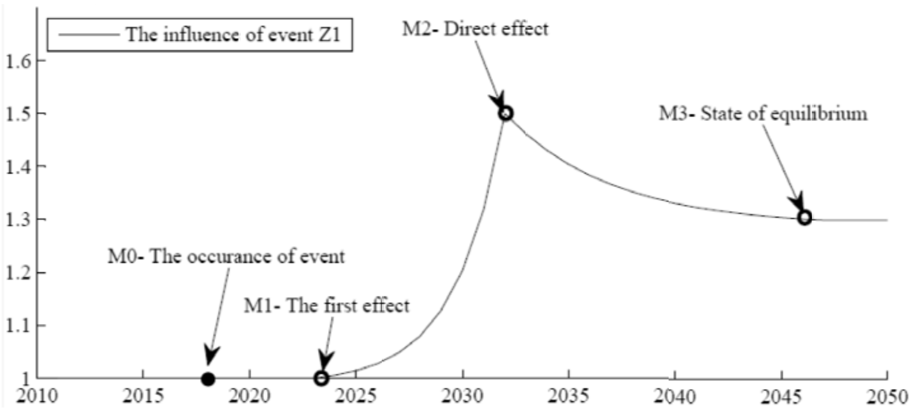

Figure 1. The influence of key event upon the basis value

Source: own elaboration.

Moment M_1 defines the time that passes from the moment of event occurrence up to the occurrence of first effects, this means period [M_0; M_1]. The separation of moment of occurrence from the observation of first effects allows for the consideration of events with a lagged influence. In the case when a given event does not show a lagged character of influence an expert may exclude this period by accepting the value of 0 for period M_1.

Moment M_2 defines the time that passes from the moment of event occurrence up to the so called direct effect, this means period [M_0; M_2]. The direct effect is a principal effect that a key event exerts upon the basis value with the exclusion of a possible lag, i.e. period [M_1; M_2].The direct effect is the time when an event should have the most significant and intensive influence on the defined basis value. For events that may occur repeatedly in the given time horizon, i.e. 2011-2050, the experts determine if the same event may not occur at the time of direct effect, namely period [M_0; M_2] (a possible length of the interval between period M_0 and period M_2 when the event cannot occur again is called the rejection threshold). In the case when the chance for the key event to occur again in the period of direct effect is blocked, the event can appear only in periods after moment M_2.

Moment M_3 defines the time that passes from the event occurrence up to the state of equilibrium or, in other words, the moment terminal level is reached. This determines the period [M_0; M_3]. The terminal level, as a result of the occurrence of key event, determines the value that will influence the basis value after all direct factors of influence have expired, when the situation is already stabilized. The expiry of influence factors is not identical to the total disappearance of influence. When determining a terminal level of influence upon the basis value, an expert takes into consideration a situation when the consequences of key event occurrence may imply permanent structural changes that have an effect on the formation of a given event and, at the same time, they may permanently change the form of basis curve. In the case when an event disappears completely and the effect of its influence fades, it is enough to adopt the value of zero for value M_3.

The division into particular sub-periods with defined values of influence in characteristic points, i.e. M_1, M_2, M_3, raises a question related to the character of formation of event within these sub-periods, this means from M_1 to M_2, and from M_2 to M_3.

The character of influence, similarly to the already determined values, is defined by experts. Having a choice of one out of three analytical forms of curves, the experts can define its character, which, according to their knowledge, will be the most appropriate in particular sub-periods. It is accepted that the curves of influence can have a linear, logarithmic or exponential form. In this research it is significant that the experts do not give any values that additionally could help in the parametric determination of considered functions and their role is limited only to the choice, on the basis of graphs, exemplary curves of the form that in the most similar way will reflect the nature of the event from the considered sub-period. Such an action has an approximate character and even though in some cases the experts would be able to give a more detailed function defined in a parametric way, the adopted methodology rejects such a possibility. The determination of parameters of selected functions is based only on the length of the considered sub-period and the difference between percentage influences for utmost moments of the above sub-period, i.e. for value M_1 and value M_2 and in the second case: M_2 and M_3.

In the next stage, the experts approximate a complex character of influence of a key event stating how many times a given event may occur with reference to the whole period 2011-2050. In this case a marginal value of 4 was adopted as a maximum number of occurrence of a given event. This results from the accepted definition of a key event as a rare event. Moreover, as has been already mentioned, the experts determine whether the event may occur in sub-period $[M_0; M_2]$ with the simultaneous lack of restrictions related to multiple occurrence of event in period $[M_2; M_3]$.

The role of experts finishes with the parametric determination of key events. Further actions and results that include the above establishments as it comes to the formation of key events depend on the properties of simulation algorithms that take into consideration the primary assumptions of the research as a whole foresight analysis.

3. Simulation process as a tool of forecast correction

This part of the article specifies simulation methods and mechanisms that serve a purpose of determining the value of forecast with the consideration of key events.

The determination of value of terminal forecast that takes into account the influence of a key event will be described in accordance with the following simulation scheme for a single iteration as well as for number *l* of key events specified by experts.

Conditionally, for a selected $m \in \{1, ..., l\}$one defines:

1. Number *k* of occurrences of a given events, according to the adopted probability distribution defined for a specific case.

2. Conditionally, for number *k* of occurrences of key event, defined in step 1, one defines years when the event will take place. These years are determined according to the adopted distribution.

3. For distinguished *k* years, when the event may occur, one defines the influence of a specified event in a sequential manner, beginning with the earliest year. Sequential proceedings in the case of events that occur more than once are aimed at the consideration of possible influence of these events from earlier periods. Ipso facto, one determines the total influence of events for *i*-iteration and *m*-event.

4. Steps 1-3 are repeated for each event. Thus, one gets *l* 40-element-sequences that describe the hypothetic influence of each of *l* events separately for one iteration within the period 2011-2050.

5. Having *l* independent which influences a single iteration, one should determine the aggregated influence in a single iteration for all events in total. In such a way one simulation step determines one scenario of the total influence of *l* key events that occurred within the period of 40 years, beginning with 2011 and ending with 2050.

The actions described in steps 1-5 of the above scheme should be repeated *n*-times. After the *n*-experiment one determines the matrix of aggregated influence that has a size of $n \times 40$, whose values state *n* possible scenarios of development of basis value in the years 2011-2050. The values in the matrix of development scenarios are expressed in units that are appropriate for the basis values defined by experts. For such a defined matrix of development scenarios of basis values it is possible to specify the basic statistic measures that describe the character of future changes within the set time horizon.

4. Adopted probability distributions

The first step of simulation task includes the determination of number k of occurrences of m-key event, which is connected with the prior specification of probability distribution, out of which an appropriate number of values will be randomized. We defined the probability of the m-event to occur k times a $P(Z_{mk})$, where $k \in \{0, ..., k_{max}\}$.

The number of occurrence of k events has been earlier limited to maximum of four. In the case when experts define the maximum number of occurrences as $k_{max} = 1$ in the period of 2011-2050, the probability of the event occurrence is defined as follows:

$$P(Z_{m1}) = 1 - \prod_{j=1}^{4}\left(1 - P(D_{mj})\right) \tag{1}$$

where $P(Z_{m1})$ is the probability of single occurrence of m-event, $P(D_{mj})$ is the probability of event occurrence in one of the four decades and index j defines the following decade.

The values $P(D_{mj}) = S_{mj} / \sum_{j=1}^{4} S_{mj}$, where S_{mj} is defined by the experts and expresses, in the form of a decimal fraction, the chances of occurrence of m-event.

In cases when the experts state that the event may occur more than once, i.e. $k_{max} \in \{2, 3, 4\}$ in the whole period of 2011−2050 the value expressed by equation (1) specifies the frequency of events in Poisson distribution.

It has been adopted in the research that initially for number of events $k = \{0, 1, ..., k_{max}\}$ the probabilities are defined on the basis of Poisson distribution. Since $P(Z_{mk})$ expresses the probability distribution, they have to sum up to unity. However, the initial values determined on the basis of Poisson distribution for $k = \{0, 1, ..., k_{max}\}$, when $k_{max} \leq 4$ will not give the value of one in total. The difference between unity and the sum of values initially defined on the basis of Poisson distribution should be properly separated so that values $P(Z_{mk})$ could form the probability distribution. The separation can be conducted between $k_{max}+1$ values evenly or proportionally to the initial values of probabilities.

On the basis of values defined by the experts, one determined the probabilities of event occurrences in particular decades; however, at this stage of the research the fundamental issue turns out to be the moment of occurrence as a single year within the period of 2011-2050. In cases when the event occurs once, it is assumed that probability distribution of the event occurrence in one of the possible years is defined directly on the basis of values of probabilities $P(D_{mj})$, for j-decade. The probability of event occurrence in the given year r is defined by $P(L_{mr}) = P(Z_{mk})/10$, where

$r = 2010 + (k - 1)10 + n$, for $n = \{1, ..., 10\}$. If the event occurs repeatedly, one should consider the multi-stage nature of the experiment. In a general case, for a specified number k-times occurrence of the event, there are 40^k possible combinations. In the utmost case for the maximum number of occurrences = 4, there are 2560000 possibilities. However, taking into account the conditions of the experiment, most of these probabilities will equal zero. This is caused by two factors:

– the event cannot occur again in the same year,
– in the case when the rejection threshold is non-zero, the number of possible years decreases in the following phases of lottery-drawing.

5. Determination of future directions of changes

The simulation task, on the basis of which the matrix of development scenarios of basis values has been determined, allows for the identification of the future forecasts of the amount of energy saving (drawn from the considered technology) with taking key events into consideration.

This task has been performed with the application of an authorial program written in the Matlab environment. The basic statistic measures determined towards columns of the scenario matrix, i.e. measures that describe the following years from the period 2011-2050, will inform about the average directions of changes and the degree of their diversity.

Below there are exemplary graphs showing the influence of key events upon the basis value, achieved as a result of simulation procedure described before. Figure 2 presents a joint character of influence of 5 key events upon the basis value on the basis of values of classic measures such as the mean and standard deviation. The average values for particular years define the correction for forecasts of the initial value with the consideration of all events in total.

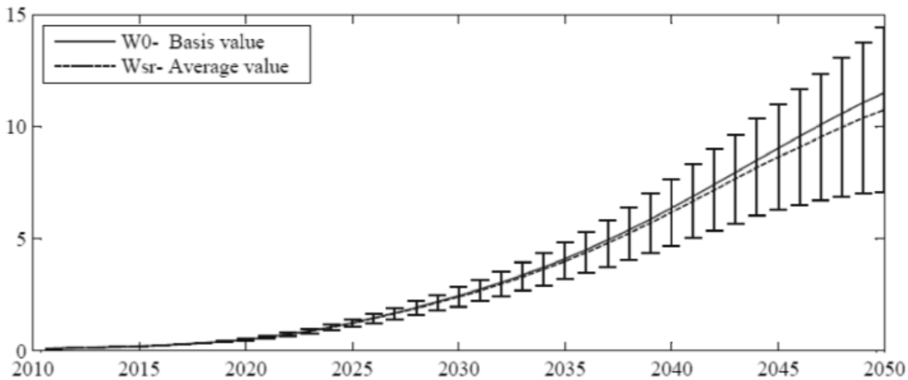

Figure 2. Total influence of key events defined on the basis of the average value

Source: own elaboration.

Line *W0* defines the basis value before the consideration of the influence of key events. Line *Wsr* marks the average value obtained as a result of simulation of total influence of events in particular years. The scopes of changes in particular years are defined as standard deviations up and down from the mean values. In the above example the key events interpreted together may have a negative influence on the basis value in future. However, based on the average value as a correction of basis forecasts, these changes will not be significant, and the values of standard deviations, especially in the final period, may suggest different scenarios of development, depending on the adopted assumptions.

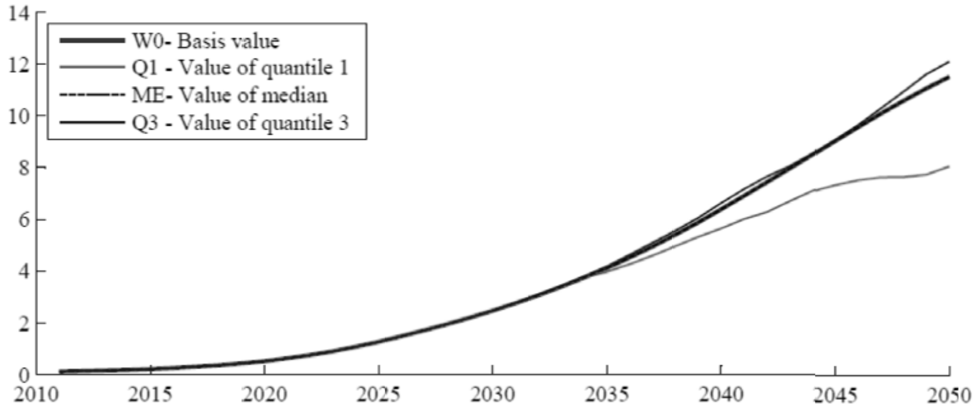

Figure 3. Total influence of key events on the basis of median together with the values of quartiles

Source: own elaboration.

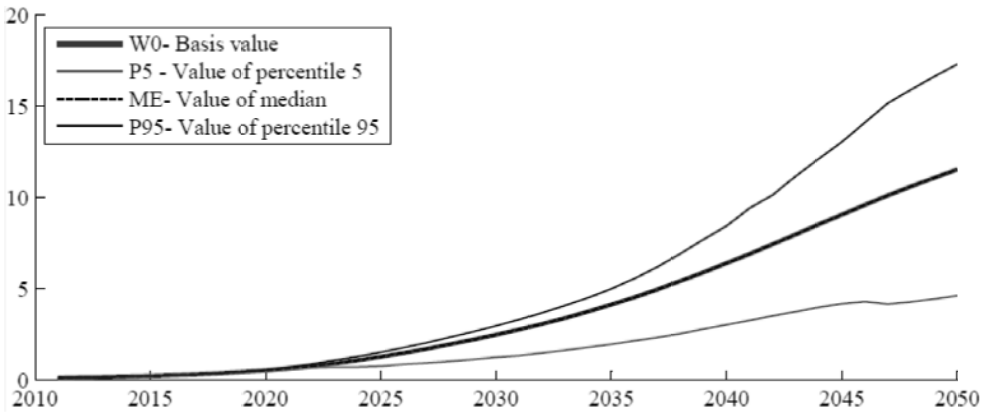

Figure 4. Total influence of key events on the basis of median together with the values of percentiles

Source: own elaboration.

In the case of application of position measures, such as median, quartile, percentile, for the same data obtained in the simulation process, proper values considered in the research have been determined. The results are presented in Figures 3 and 4.

In Figure 3 and 4 the value of median agrees completely with the value of basis curve which suggests the case when total influence of key events may be reciprocally leveled in the most optimistic version. Nevertheless, analyzing the values of quartiles, it can be seen that future key events tend to decrease the basis values. Additionally, this process may show the trend to intensify in the final years of the forecast. In the case of percentiles, the scope of variation is so big that practically only the borders of variation for utmost scenarios can be determined which in the case of defining future directions of development and identifying optimistic or pessimistic scenarios may be fully sufficient.

6. Conclusion

The presented methodology allows for the consideration of key events in the decision-making process. The forecasts of proper values that take into account the events with a specific significance have a broader practical application in the case of long time horizons for which they are defined. The application of simulation methods allows for the performance of a wide range of additional studies, such as the analysis of solution sensitivity with regards to the adopted sub-sets of key events in relation to the initial solution and, at the same time, determination of events with the strongest influence. This enables us to specify optimistic and pessimistic scenarios that take into consideration only these events with a determined character of influence upon the studied value. All these pieces of information used in foresight studies will allow for a better definition of future strategic aims on the basis of defined forecasts, where an additional bit of information drawn from analyses that consider the influence of key events will make it possible to make the right decisions including both future chances and threats.

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ZASTOSOWANIE METOD SYMULACYJNYCH JAKO NARZĘDZIA DO KONSTRUKCJI EKSPERCKICH PROGNOZ DŁUGOOKRESOWYCH

Streszczenie: Zastosowanie metod symulacyjnych pozwala na uwzględnienie wpływu zdarzeń o kluczowym znaczeniu w przypadku wyznaczania prognoz długookresowych. Oddziaływanie zdarzeń na wielkości bazowe o różnym charakterze, sile wpływu, częstotliwości ich występowania, czy momencie wystąpienia, może być trudne w przypadku budowy klasycznego modelu. Podejście symulacyjne daje możliwość nie tylko określenia łącznego wpływu, ale także uwzględnienia szczególnych przypadków i przeprowadzania szeregu testów diagnostycznych weryfikujących siłę oddziaływania przyjętych hipotez. Przyjęta metodologia wyznaczania prognoz może być stosowana nie tylko w badaniach o charakterze *foresight*, jednak pierwotnie została stworzona dla nichi w nich może znaleźć najszersze zastosowanie.