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ANALYSIS OF WEATHER RISK IN AGRICULTURE AS AN IMPORTANT PART OF ADAPTATION TO CLIMATE CHANGE

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ANALIZA RYZYKA POGODOWEGO W BRANŻY ROLNEJ JAKO ISTOTNY ELEMENT DZIAŁAŃ ADAPTACYJNYCH DO ZMIAN KLIMATU

STRESZCZENIE: Z każdym rokiem zmiany klimatyczne nabierają na sile. Jednym z nadrzędnych celów Unii Europejskiej jest ograniczenie emisji gazów cieplarnianych. Jednak należy pamiętać, że nawet jeżeli emisja dwutlenku węgla zostanie obniżona do deklarowanego poziomu to i tak niektóre zmiany klimatu są nieuniknione. Dlatego już teraz powinny być podejmowane działania, które pozwolą przystosować się zarówno gospodarce społeczeństwu, jak i środowisku do nowej rzeczywistości.

Celem artykułu jest przedstawienie kroków analizy ryzyka pogodowego, jakie powinno podjąć przedsiębiorstwo rolne aby skutecznie zarządzać ryzykiem pogodowym, co stanowi nieodłączny element działań adaptacyjnych do zmian klimatu. Aby podkreślić istotność omawianego tematu, biorąc pod uwagę koncepcję zrównoważonego rozwoju, na wstępie omówiono społeczny, ekonomiczny i środowiskowy wymiar zmian klimatu. Następnie przedstawiono metody identyfikacji ryzyka pogodowego, elementy efektywnego zarządzania ryzykiem pogodowym w rolnictwie, proponowane zabezpieczenia finansowe i fizyczne, tak aby na końcu zaprezentować schemat analizy ryzyka pogodowego w przedsiębiorstwie rolnym.

SŁOWA KLUCZOWE: ryzyko pogodowe, zmiany klimatu, branża rolna, analiza ryzyka

Introduction

Weather conditions have a significant impact on business, when analyses are done at both a macro and micro scale. Advancing climate change has caused weather anomalies to became a reality. The variability and unpredictability of weather has become a part of everyday life.

Due to the increasing number and scale of extreme weather conditions, the governments of many countries are being forced to implement adaptive measures against climate change. These include the financial and physical support of citizens in the event of a disaster, as well as activities connected with the preparation of infrastructure in the event of extreme weather phenomena. The economy of a country affected by a natural disaster is exposed to a huge loss. This comes not only from the physical destruction caused, but also by a supply shock, or the redirection of national investments from production activities to disaster effect mitigation.

In addition to energy and construction industries, agriculture is listed as one of the most vulnerable to the negative impact of weather conditions, as the majority of its activities are performed outside.

The aim of this article is to present the steps of weather risk analysis that an agricultural enterprise should take in order to manage weather risk effectively. This is an integral part of adaptation measures to climate change. To emphasise the importance of this subject, the social, economic and environmental dimensions of climate change are discussed in the introduction, taking into account the concept of sustainable development. Then, we present weather risk identification methods, the elements of effective weather risk management in agriculture, and the proposed financial and physical protection from these risks. This allows us to present the overall scheme of weather risk analysis in agricultural enterprise.

Social, economic and environmental dimensions of climate change

When making analyses concerning the effects of climate change, one generally emphasises their economic dimension, however, omitting the social and environmental effects, which are no less harmful. The European Union estimates that the lack of action to reduce the negative impact of weather on investments and business will cost the European economy around 100 billion

euros per year until 2020; by 2050, this amount could rise to 250 billion EUR per year[1].

The most dangerous consequence of climate change are weather anomalies. Since 1980, 90% of natural disasters have been directly or indirectly caused by weather and climate[2]. Economic losses due to extreme weather events (mainly floods and droughts) in the period 1974–2006 in Albania amounted to 69 billion USD, in Bosnia and Herzegovina 23 billion USD, in Bulgaria 15 billion USD, in Croatia 34 billion USD, in Romania 293 billion USD, in Serbia 82 billion USD, in Slovenia 7 billion USD, and in Turkey 561 billion USD[3]. In Poland, from June to August 2009 the reported losses were estimated at 64 thousand PLN. In the years 1997–2008 the government allocated 600 million PLN for assistance measures for victims; in 2008 alone, this figure was more than 52 million PLN[4].

Another consequence of climate change is a change in weather characteristics, which is non-catastrophic weather risk that requires changes in production methods. It can even result in the complete cessation of production, which in the new weather conditions proves to be unprofitable.

Among the sectors that will lose the most thanks to progressing climate changes are agriculture, energy and tourism. In agriculture, projected climate changes will affect crops, livestock management and the location of production. The increasing number and scale of extreme phenomena will significantly increase the risk of unsuccessful harvests[5]. Climate changes will cause significant changes in the quality and availability of water resources, affecting many sectors, including food production.

In the energy sector, climate change will have a direct impact on both energy supply and demand. The forecasts concerning the impact of climate change on precipitation and melting glaciers show that in Northern Europe, an increase in hydropower production of at least 5% is possible, and in Southern Europe there could be a decline of at least 25%. It is also expected

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1 *An EU Strategy on adaptation to climate change,* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2013) 216 final, Brussels 16.04.2013, p. 20.

2 *Impacts of Europe's changing climate. An indicator-based assessment*., EEA Report 2004 No. 2, p. 16.

3 *Economic loss of other perils is also included for calculating annual average economic loss*, from EM-DAT, National Geophysical Data Centre website, GDP – World Bank statistics, Brussels 2007.

4 Z. Jęska, *Sektor ubezpieczeń wobec rosnących strat powodowanych przez gwałtowne zjawiska pogodowe,* Warszawa 2009, www.koalicjaklimatyczna.org [15/02/2014].

5 www.klimada.mos.gov.pl [02/02/2015].

that decreased precipitation and heat waves will negatively affect the cooling process, and thus the performance of power plants[6].

The tourism sector is likely to suffer from decreasing snow cover in the mountains, and an increase in air temperature in the traditional areas of recreation on the shores of warm seas.

Changing weather conditions have a significant impact on society, especially on human health. With the increase in frequency of extreme weather phenomena, there might be an increase in deaths and diseases related to weather conditions, such as excessive mortality due to heat, the occurrence of invasive carriers of infectious diseases, and an earlier start and increased seasonal production of allergenic pollen, especially in the high and mid-latitudes of northern hemisphere.

The social costs of climate change should include those which cannot be converted into money, including, among other things, an increase in child mortality in developing countries, conflicts caused by migration, competition for raw material sources and work, deterioration of educational opportunities, and gender equality[7].

Climate change is affecting, and will impact on, the range and distribution of species, their reproductive cycles, growing seasons and interactions with the environment. Many species of animals and plants may become extinct as a result of climate change limiting the diversity of habitats and mobility. The most vulnerable species are living in the Antarctic zone, for instance polar bears, as well as alpine and marine species, such as coral reefs, jellyfish and microplankton[8].

Among the effects of climate change on the environment, the impact on coastal and marine ecosystems should be mentioned. The coastal erosion phenomenon will increase, and existing protective measures may be insufficient to prevent the flooding of coastal areas in many regions[9].

Weather risk identification methods

While analysing weather risk identification methods, the first thing one should do is divide the risk into catastrophic risk and non-catastrophic risk. Catastrophic weather risk is the danger associated with the occurrence of extreme weather phenomena such as hurricanes, floods, torrential rains, hail, snow storms, or extremely high temperatures. Whereas the concept of

6 Ibidem.

7 Stern Review: The economics of climate change, Part I, London 2006, p. 20.

8 J.D. Sachs, *Common wealth: economics for a crowded planet*, New York 2008, p. 88.

9 www.klimada.mos.gov.pl [20/03/2015].

non-catastrophic risk is used to describe the financial consequences for businesses caused by events as heat, cold, rain, snow, or wind[10].

Depending on the sort of weather risk one faces, appropriate methods of identification and measurement must be adjusted to it, and in addition to this one should consider the protection of activities, using the instruments dedicated to a particular type of weather risk.

Identifying weather risk for a company involves creating a list of potential weather phenomena that may affect its revenues or costs. Risk is measured by determining the amount of expected losses caused by given weather events in monetary units. In general, adverse weather conditions can be divided into those in which their parameters and effects are known, and those with unknown parameters and/or effects.

Effective management of weather risk in enterprise is a very complicated process. In the case of catastrophic weather risk, the very identification of weather anomalies that the enterprise is exposed to is the problem, and predicting the potential losses caused by them (mainly because of their unpredictability and violent character). When analysing non-catastrophic risk, the same weather events that generate losses for one entity may be beneficial to another. Another method of risk identification involves historical data analysis. Historical financial time series can be tested to identify the causes of any changes occurring in them. More specifically, one should answer the question of whether these changes were caused only by the influence of weather events. Other important factors, such as, market share (or the number of customers), the price of complementary and substitutive goods, and the market price of goods or services should be removed from the initial data. The biggest problem during this process is the availability and quality of financial historical data[11].

Agricultural industry and the weather risk

A very dangerous consequence of advancing climate changes for agricultural sector enterprises are extreme weather phenomena. Drought or flood can destroy hectares of cultivated fields, and lead to bankruptcy of many agricultural entrepreneurs. The amount of rainfall often has a decisive impact on the quantity of harvested crops. Insufficient rainfall (not just the lowest leading to drought) delays plant growth, and can even lead to their total destruction. Too much rain reduces plant growth, and during the harvest

10 R.B. Connors, *Weather derivatives allow construction to hedge weather risk*, "Cost Engineering" 2003 No. 45(3), pp. 21–24.

11 Ibidem.

hinders work on the fields. Higher than expected temperatures can also significantly affect agricultural productivity, agricultural income and food security. Overly high temperatures during crop trimming can adversely affect the physiological processes of plants, such as the development of leaves and grains, and reduced viability of pollen and grains during flowering[12].

Climate change threatens agricultural biodiversity. The IPCC predicts that 20–30% of plant and animal species will be threatened with extinction if the air temperature on Earth rises by 1.5–2.5°C[13]. The new climatic conditions will also contribute to increase in the amount of weeds, insects, and diseases of plants and animals. New species of pests and infectious diseases may also appear[14].

The risk of climate change in the agricultural sector may influence the number of negative events that occur, such as the depletion of supplies (damage to or loss of crops), price fluctuations, the risk of bankruptcy of agricultural enterprises, and a reduction in their productivity and profitability.

Non-catastrophic weather risk influences the supply and demand of the agricultural sector. In 2003, 64% of wheat crops in Ukraine were destroyed by low temperatures, while in England, 40–50% of the production of rapeseed oil was destroyed as a result of excessive rainfall during harvest. The weather can affect not only the quantity but also the quality of agricultural production. An example is the cultivation of barley used for beer production. A key factor influencing the quality of the barley might be rain occurring during harvest – rain leads to change in the colour and reduction of grains. A brewery that does not have barley of sufficient quality, must purchase it at market prices, which is associated with additional costs. On the demand side, the impact of weather is associated also with quality. In order to deal with new weather conditions, agricultural producers use agricultural chemicals. These are pesticides, artificial fertilizers and agricultural protection measures, which reduce the quality of sold agricultural products[15].

Another important issue, is taking into consideration the weather conditions when designing local budgets, which allows one to specify in what way the government recognises the problem of weather risk. As indicated by the OECD (*Organization for Economic Co-operation and Development*) the

12 D.S. Battisti, R.L. Naylor, *Historical warnings of future food security with unprecedented seasonal heat*, "Science" 2009, pp. 240–244.

13 IPCC (Intergovernmental Panel on Climate Change), Mitigation. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, Climate change 2007: contribution of Working Group III to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press 2007 (www.ipcc.ch [10/04/2015]).

14 J.M. Hall-Spencer, R. Rodolfo-Metalpa, *Volcanic carbon dioxide vents show ecosystem effects of ocean acidification*, "Nature" 2008 No. 454(7200), pp. 96–99.

15 www.guaranteedweather.com [22/01/2015].

government has a duty to support farmers in risk management that should focus on catastrophic weather risk. According to the OECD, the likelihood of extreme weather events is rare, but if it occurs, it causes huge damages, simultaneously, in the homesteads of many farmers. The primary task for the government is, through training and information campaigns, to raise the awareness of climate change and the impact of weather on agricultural activities in entrepreneurs in the agricultural sector, and to provide adequate instrumentation to help manage this risk. The OECD emphasizes the importance of well-designed contingency plans in the event of a disaster, which determine the scope of responsibilities for both governments and entrepreneurs[16].

Weather risk management in the agricultural enterprises

The process of weather risk management in the agricultural enterprise should include the following steps[17]:

1. Risk analysis – identifying the impact of weather risk on agricultural production, determining the probability of an event and determining both the consequences of an incident and quantitative determination of the impact of adverse weather conditions on the revenue of a given agricultural enterprise.
2. Formulating conditions – identifying possible alternatives as well as outlays and costs of particular solutions.
3. Risk assessment – declaring readiness, determining the ability of the entity to risk, determining the actual level of risk, qualification of solutions to control risk.
4. Risk control – tool selection, prioritisation and applying the optimal combination (including choosing the right kind of physical and/or financial protection).
5. Control, monitoring and evaluation of activities – assessing the impact of the effects of taken measures, when the decision is wrong – new arrangement of risk management process and the use of tools that would ensure the success of management.

Identifying the impact of weather risk for a particular production comprises three stages: identifying areas of production exposed to the negative

16 J. Anton, *A Comparative Study of Risk Management In Agriculture under Climate Change,* in: OECD Food. Agriculture and Fisheries Papiers, No. 58, OECD Publishing 2012, p. 42.

17 T. Kaczmarek, *Ryzyko i zarządzanie ryzykiem. Ujęcie interdyscyplinarne*, Warszawa 2006, p. 34.

impact of weather, identifying the period in which the weather can affect a particular agricultural production and determining which weather factor (temperature, precipitation, or wind) can lead to lower quality and quantity of agricultural production.

In quantifying the impact of adverse weather conditions on an agricultural enterprise, there are two possible approaches. The first involves determining the extent to which the entity is exposed to financial losses due to the negative impact of a given atmospheric factor. In the second, the limit is set; this is the maximum financial protection needed to cover any potential losses caused by the weather event. These approaches, depending on the weather factor that negatively affects the business, can be used interchangeably or in combination.

To calculate the financial effects of a given weather event[18] for a certain agricultural production, one can determine a financial equivalent, which determines the degree of vulnerability of the agricultural enterprise for a given weather event. For this purpose, one may, for example, take into account production costs or consider the anticipated revenue from the sale of a harvest, which is especially authoritative for producers with fixed price contracts or for those who use price risk management instruments[19].

If the price is not known, one needs to estimate (using the regression line, historical data relating to a given weather factor and agricultural production, e.g. sales revenues, the amount of produced agricultural product), how a given weather event affects the size of agricultural production and how in the final effect it may affect the achieved revenue. In other words, one needs to estimate how much the revenue will change if a given atmospheric factor works, for example, how much the revenues of a given homestead will change if the temperature during the growing season of plants drops by 10°C. In order to determine the maximum value (limit), which the agricultural producer may lose, one can take into account the costs incurred by the company in the event of total crop failure (the incurred costs of agricultural production and the value of lost revenues), or one should analyse historical data of an agricultural enterprise and find the worst result achieved by the company (the lowest production or the lowest revenues).

When the company receives an answer to the question of the extent to which its production is exposed to the negative impact of a particular weather factor in a given period, one should secure it physically and/or financially.

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18 Weather events can be both catastrophic and non-catastrophic in nature.

19 T. Kaczmarek, op. cit., p. 35.

Financial solutions

When analysing financial protection against the negative impact of weather on the agricultural sector, one should use the division of risk into catastrophic and non-catastrophic risk. In case of catastrophic risk, a dedicated tool is provided by traditional insurance policies.

Comparative analysis of already existing agricultural insurance schemes shows large differences between particular countries. Governments in many countries support the creation of systems to insure crops and livestock, treating it as a form of subsidies and support for the development of agriculture. Insurance of basic crops often operates as mandatory insurance, or in connection with loans provided to homesteads, both ordinary and partly refundable by individual governments. Moreover, in many countries, every year so-called "disaster funds" are decreed and managed by the governments.

In the USA there is no insurance for specific risks, but crop insurance covers most of the risks, from the primary or catastrophic coverage, which guarantees 50% of the average yield of the homestead, up to 80 or 100%[20]. In the USA, both revenue and income insurances operate. The majority, 73%, of contributions comes from revenue insurance products, which include: revenue insurance by indexed area, the price of livestock insurance, gross margin insurance of inventory and income insurance of the entire homestead. Three standard insurance revenue products are *Crop Revenue Coverage* (CRC), *Revenue Assurance* (RA), and *Income Protection* (IP).

In the USA approximately 45% of cultivated field production is insured (in the EU 23%). The average contribution rate is close to 9%, which is much higher than in Europe (4%), mainly because of the fact that insurance offers broader coverage: revenue or yield insurance versus mainly insurance of one risk. Total support of insurance by the US government is 72% of all contributions (in the EU around 500 million EUR = support 32%)[21].

While comparing insurance schemes, it may be noted that in the European crop insurance it is necessary to establish which risk resulted in a loss, while US multi-peril crop insurance (MPCI) includes the loss of crops due to plagues and diseases, and damages are calculated simply as the difference between the guaranteed and actual yield.

In the Czech Republic, Bulgaria, Hungary, Portugal, Slovenia, and Sweden, combined risks insurances are accessible (as in Poland). The main products available for Belgium, Germany, the Netherlands and the UK are insurances against hail or one-product insurances. The demand for other products is

20 E. Wojciechowska-Lipka, K. Rojewski, L. Rybak, *Ubezpieczenie upraw w USA, Prawo, Reasekuracja, Ubezpieczenia*, Warszawa 2002.

21 Ibidem.

irrelevant. There is no public support for insurance. In some northern countries, there is less demand for crop insurances, or they have only begun to develop their systems (Latvia and Lithuania). In Finland, private crop insurance is less developed, but there is a public „Crop Compensation Program" designed to compensate for crop losses after natural disasters[22].

In France, the government finances the purchase of 50% of crop insurance. French insurance companies insure crops only from hail (corn and sunflower also against hurricane risk). In the event of a natural disaster, a condition to receive help is to have a complex property, and crop insurance and the minimum loss of the harvest of a given crop must be in the region of 27%, or 14% for the whole farm[23]. In Greece, crop insurance is also mandatory and costs 3% of the turnover of the farm. This insurance protects the crops against the effects of almost all natural risks and the upper limit of compensation is up to 70% of the damage. In the UK and Italy, the crops are insured from hail only (subsidised from the national budget in the amount of 50% of contributions); other risks concerning crops are seen as uninsurable. In these countries, assistance to victims of natural disasters occurs in the form of low-interest loans and subsidies, emergency assistance and recovery of losses of crops, tax rebates and deferrals of tax payments, and taking over the liabilities on account of social insurance. Aid is given to homesteads affected by natural disasters when the damage exceeds 35% of the harvest in a given area[24].

The issue of crop insurance and its high price in Poland is regulated by law. Moreover, in insurance companies offers there are insurances designed specifically for farmers that additionally and voluntarily allow to protect one's business. In Poland, every farmer is obliged to purchase the following compulsory insurances[25]:

1. liability insurance of farmers on account of the ownership of a farm, known as *ubezpieczenie OC rolników* (Eng. third party liability insurance for farmers),
2. insurance of buildings constituting the farm against fire and other random events, called *ubezpieczenie budynków rolniczych* (Eng. the insurance of agricultural buildings).

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22 M. *Łozowski, Z. Obstawski, Podstawy budowy Wspólnego Systemu Ubezpieczeń Rolnych w Unii Europejskiej*, "Zeszyty Naukowe SGGW, Polityki Europejskie, Finanse i Marketing" 2009 No. 2(51), p. 190.

23 J. Baranowski, *Surowy sprawdzian polskich ubezpieczeń rolnych*, "Fair Magazine" October 1997, pp. 51–52.

24 M. *Łozowski, Z. Obstawski,* op. cit., pp. 192–193.

25 I. Ługiewicz, M. Szymański, *Minimalizacja ryzyka w gospodarstwach rolnych. Ubezpieczenia w zarządzaniu ryzykiem*, Toruń 2010, p. 183.

In addition to compulsory insurance, insurance companies offer voluntary insurance. These include insurances of movable property, livestock, agricultural machinery and equipment, agricultural products, supplies, means for crop and animal production and crop production in progress in the event of a weather event[26]. Insurance companies define weather events differently, and they determine different sums of insurance, insurance coverage, amounts of compensations, and policy conditions. This is a very big obstacle for the enterprise wishing to protect its business against catastrophic weather risk.

Instruments dedicated to non-catastrophic weather risk are weather derivatives. Weather derivatives are bilateral future contracts that are settled on the basis of weather conditions[27]. A classic derivative weather instrument can be described by the type of contract. This may be a forward/futures, option or swap contract.

Contracts for weather derivatives can be concluded on the stock market or OTC market. Currently the stock market in the world is created mainly by the stock exchange *Chicago Mercantile Exchange*, which quotes the option and futures contracts for 35 locations in the world (excluding Poland) mostly based on the index of temperature.

The OTC market is the market of „tailor-made" contracts for specific businesses. Therefore, the mechanism and parameters of settling a given contract may take any form[28].

So far in Poland, no weather derivative contracts have been signed. Market development of weather derivatives in Poland may be completed in several ways. The first is the introduction of indexes based on weather conditions to trading on the Warsaw Stock Exchange. This will allow for the use of existing technical and organizational infrastructure in the field of stock market derivatives.

This instrument can be traded also on the OTC market by organising a web-based platform, taking into account weather derivatives in the offer of the interbank OTC market by financial institutions serving large companies from branches particularly exposed to the weather risk or by organising a specialised market of weather derivatives by the companies interested in limiting the weather risk.

In Poland, the only company having the instrument of weather derivatives in its offer is Consus S.A. Consus S.A. has its headquarters in Toruń, while regional offices are located in Łódź, Katowice and Szczecin. The

26 Ibidem, p. 184.

27 www.consus.eu [07/10/2014].

28 J. Preś, *Wybrane metody oceny ofert zabezpieczenia finansowego częściowego lub całkowicie opartego na indeksach pogody*, Szczecin 2009, pp. 1–2.

company specialises in the sale of weather derivatives in Poland and Europe. The company Consus is also, as the only company in Poland, a member of the international Weather Risk Management Association: WRMA. Until now, the company Consus S.A. has not entered into any weather contract in Poland. It is a company known only from the sale of rights to emit carbon dioxide.

Physical solutions

In the agricultural sector, the development of technology and innovation plays an important role among the adaptation measures to climate change. Introducing new crop varieties and production techniques, and conservation techniques of agricultural production can offer the potential to improve efficiency in the face of new weather conditions.

Examples regarding the physical protection of agricultural production against non-catastrophic weather risk are presented below:

- the risk of frost damaging the vegetation of plants – depending on the size of the crops, one may protect it by covering it with straw, leaves, branches of coniferous trees, nonwoven fabric (agro nonwoven fabric), bark, peat, sawdust (applied especially for the cover of tree roots in the orchards);
- the risk of too much sun – shield made of a shading net;
- the risk of excessively high temperatures – special irrigation systems;

When the strength of the prevalent weather conditions accumulates and leads to occurrence of extreme weather values, agricultural enterprises can benefit from the solutions presented below:

- flood risk – levees, appropriate landform allowing for water drainage, attention to proper functioning of drainage ditches, and possession of water drainage devices;
- risk of drought – special irrigation systems of fields;
- the risk of damage caused by strong winds – depending on the type and size of the crops, good solutions may be live hedges, planting coniferous trees alongside crops and shading net.

Depending on the region and the type of weather risk and a particular event, agricultural enterprise should use other solutions, physically protecting their production against the negative influence of weather conditions.

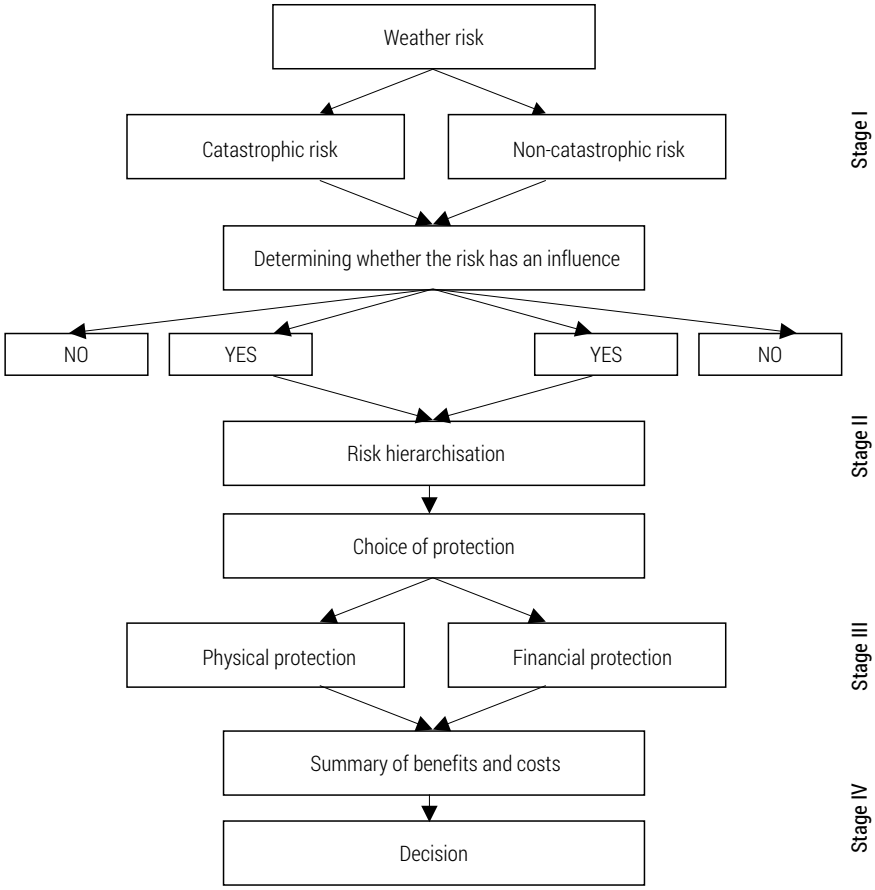

Figure 1. Schematic analysis of weather risk in the agricultural company

Stages of weather risk analysis

Stages of weather risk analysis in the agricultural company are shown in Figure 1. The primary objective of the first stage is to determine whether, and to what extent weather conditions affect the revenue or the amount of agricultural production. This stage is followed by the hierarchisation of weather risk, which allows one to select the appropriate protection tool.

If in the first stage, it turns out that there is a probability of occurrence of extreme weather phenomena, one should calculate the maximum value that a farm business may lose as a result of weather anomalies. To determine whether an agricultural enterprise is exposed to the negative impact of non-catastrophic weather risk, one should examine in what way the average

monthly temperature, average monthly precipitation and average monthly wind speed will be affected and how this will affect its revenue and/or quantity of production.

To determine the hitherto impact of non-catastrophic weather risk on agricultural production, one can use the method of least squares[29]. In this study, for the amount of produced agricultural production or the amount of sales, one uses single-equation linear econometric model in a general form:

$$Y_t = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon_t,$$

where:

Y_t – the quantity of produced agricultural production/revenues from sales of agricultural production,
X_1 – temperature [°C],
X_2 – precipitation [mm],
X_3 – wind speed [km/h],
α_0 – free term,
β_1, β_2, β_3 – parameters standing by explanatory variables.

The results obtained from the model will answer the question, how the amount of produced agricultural production or the amount of sales will change if the temperature changes by 1°C, precipitation by 1 mm and wind speed by 1 km/h.

Using econometric models can also forecast the future value of sales of agricultural products with changes in meteorological values. Preliminary research shows that after substituting the forecasted Y value to the regression model of agricultural enterprise seasonality occurs. Therefore, models of seasonal fluctuations will be used for the forecasts. The most commonly used method in this analysis is the indicator method. It involves setting indices of seasonality for the individual phases of the cycle.

After evaluating vulnerability to a given weather risk, one should prioritise the risks on two levels. The first, in which one must indicate the place in the hierarchy of weather risk among other risks that accompany a given agricultural production. The second, that should determine the place of the weather risk in the hierarchy of among other types of weather risks. Taking into account the weather risk by ordering the risk factors from the most to

[29] The method of least squares (full name: the method of least squares of errors) is a standard method of approximation of solutions of overdetermined systems, i.e. sets of equations in which there are more of them than variables. The name „least squares" means that the final solution by this method minimizes the sum of error squares by solving each of equations. It aims to lay the regression line, the trend line for the collected data. It is used both for the estimation of the linear as well as non-linear dependency. Source: A. Welfe, *Ekonometria*, Warszawa 2003, p. 30.

least important, one should consider risk factors that cause higher losses as the most important. Due to the difficulty of determining the likelihood of weather risk, the method of risk hierarchisation, in which the most important risk factor is the one having the most significant probability, is not appropriate. What is worth emphasising, is that the difficulties with determining the probability of a given weather event are often the cause of passivity in taking safety measures.

Stage three is the choice of the right securing tool (physical and/or financial protection), which requires the determination of costs and benefits. In this, there is an identification of available governmental instruments to support management of weather risk in the agricultural company.

Finally, one should compare the costs with the benefits, that is, to answer the question of whether it is profitable to invest the funds for the purchase of the insurance.

The above mentioned stages of weather risk analysis allow the agricultural enterprise to answer the following questions: Will it be profitable to purchase weather insurance in the case of a particular agricultural enterprise? Should the enterprise invest funds for the physical protection of agricultural production and/or the purchase of new technological solutions? Should the enterprise stop or reclassify a given agricultural production for better adapted to new weather conditions?

Conclusions

Essential elements of the effective weather risk management in agriculture are:

- reliable weather forecasts, meteorological measurements at the local level;
- analyses of climate data;
- analyses of the existing relationships between individual crops and meteorological conditions – data on the effects of the conditions on agricultural production (historical meteorological data are essential for conducting analyses – average, minimum, maximum temperature, rain, wind speed, information about the dry and wet periods, knowledge about local conditions – local environmental conditions, agricultural practices, production systems, market prices, the costs of entering the market, used agricultural practices, specific problems of soil);
- analyses of climate threats and assessment of the effects of climate changes – climate change scenarios;

- available modern technologies and innovations, including early warning systems;
- economic and econometric models that allow to forecast the size of agricultural production, depending on the impact of a particular meteorological factor;
- available protection tools (such as weather derivatives and agricultural insurance) and financial tools (for example, loans on preferential terms available to agricultural enterprises affected by a climatic catastrophe);
- activities supporting adaptation to climate change carried out by governmental institutions (including operational scenarios in the event of weather anomalies, contingency plans and raising awareness of agricultural enterprises on the impact of weather conditions on the business and ways to manage weather risk, increasing aversion to risk;
- developed information networks.

The above mentioned elements constitute a generalised picture of risk management in the agricultural company. Effective management of weather risk requires an individual approach to each type of the agricultural enterprise. It depends on the type of soil and crop – different stages of plant growth, harvest, and thus other types of hazards. The presented scheme is a compilation of all the necessary elements of conscious weather risk management in the agricultural company and it may significantly help to carry out activities regarding the adaptation of Polish agricultural enterprises to climate change.

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