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Technical Note

A Vulnerability Analysis of Business to Climate-Related Hazards

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Abstract In recent years, a sharp rise in the frequency and intensity of climate-related hazards is observed worldwide. This increases the vulnerability of businesses to climate-related hazards, which in turn adversely affects the economic and sustainable development of the companies. The aim of this paper is to propose an approach for vulnerability analysis of businesses to climate-related hazards. It is assumed that the level of vulnerability for each business depends on the levels of the potential impact of the specific climate-related hazards in the given geographical region. The potential impact depends on the levels of a business's sensitivity and exposure to climate-related hazards. The approach consists of several steps. For each of the variables related to the vulnerability, five levels are defined (Very low, Low, Middle, High, Very high). The usefulness and peculiarities of the proposed approach for vulnerability analysis of businesses to climate-related hazards are validated with particular examples. The proposed approach for vulnerability analysis can successfully help the managers to make informed decisions about the choice of targeted measures to adapt businesses to climate change.

Keywords: vulnerability analysis, sensitivity, exposure, businesses, climate-related hazards, climate change adaptation

1. INTRODUCTION

Nowadays, a sharp rise in the frequency and intensity of climate-related hazards is observed worldwide (IPCC WGII AR6 2022; UNISDR 2019). Some of the most common climate-

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related hazards are extreme rainfall and temperatures, storms, floods, forest fires, landslides, drought (EEA 2021).

Numerous scientific studies prove that climate change creates a number of problems for the economic development of any country in general and, in particular, for the sustainability of individual business companies (Allen 2020; Fujita, Hatayama 2022). Therefore, solving climate problems and ensuring climate resilience on a global scale is becoming increasingly urgent today (Tanaka, Shiiba, Huang 2021; Advisory team of the World Bank 2018).

In this regard, the European Environment Agency activates the European Internet Platform for Adaptation to Climate Climate-ADAPT (EEA 2021). In April 2013, the "An EU Strategy for Adaptation to Climate Change" is adopted (EC, 2013).

In October 2019, the Council of Ministers of the Republic of Bulgaria approved the National Strategy, Program and Action Plan for adaptation to climate change of the Republic of Bulgaria (CM - Bulgaria 2019). The strategy defines a framework for actions to adapt to climate change, as well as priority directions until 2030. A comprehensive policy of the Republic of Bulgaria in the field of natural and ecological disasters was also approved (Dimitrov, Velikova, Bogomilova 2022).

In February 2021, the European Commission released a communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions titled "Forging a Climate-Resilient Europe – The New EU Strategy on Adaptation to Climate Change" (European Commission 2021a).

In this regard, it is important to emphasize that a vulnerability analysis of businesses to climate-related hazards is an important initial step for determining the adequate adaptation measures that should be additionally taken.

It is known that there are many definitions of vulnerability in the scientific literature and specialized normative documents.

Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time. In the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (in Annex II: Glossary) the vulnerability is defined as the “propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC 2022a). In this context, exposure is defined as “the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected. Potentially affected places and settings can be defined geographically, as well as more dynamically, for example through transmission or interconnections through markets or flows of people”.

According to the Terminology of the United Nations Office for Disaster Risk Reduction (UNDRR 2017), the vulnerability is "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards".

A definition for vulnerability is given in the European Commission Notice "Technical guidance on the climate proofing of investments in infrastructure in the period 2021-2027" as follows: "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity". The variables related to vulnerability - sensitivity and exposure are defined as follows: "Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (*e.g*. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (*e.g.* damages caused by an increase in the frequency of coastal flooding due to sea-level rise)." and "Exposure is the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected." (European Commission 2021b).

In this study, Vulnerability *(V)* is assumed to be a function of two main variables: Sensitivity *(S)*, and Exposure *(E)* or V = F *(S, E)* (European Commission 2021b).

The aim of this paper is to propose an approach for vulnerability analysis of the businesses to climate-related hazards. It is assumed that the level of vulnerability of the businesses depends on its levels of business sensitivity and exposure of the specific climate hazards in the given geographical region. The proposed vulnerability analysis includes several predefined steps.

2. ESSENCE OF THE APPROACH FOR VULNERABILITY ANALYSIS OF THE BUSINESSES TO CLIMATE-RELATED HAZARDS

The proposed approach for vulnerability analysis is based on the approach described in (Zlateva, Hadjitodorov 2022). This first approach has been successfully applied to analyze the vulnerability of critical infrastructure to climate hazards using publicly available open data and expert knowledge. Both approaches use the same definition of vulnerability as a function of relative sensitivity and exposure of the geographic region to specific climate hazards. The current approach is an adaptation and further development of the first approach in relation to the specific features of business companies.

Here, the approach for vulnerability analysis of the businesses to climate-related hazards is performed in several steps as follows:

2.1 Description of the Monitored Business

A description of the activities the monitored business, the economic sector to which it belongs, business relationships with other companies, tangible assets on the site, supply chains, resources (for operational and additional activity, inputs such as water and energy, *etc*.), outputs such as products and services, access and transport links and other specific characteristics.

2.2 Description of the Location of The Monitored Business

A description of the geographic region of the location of the monitored businesses is presented as follows: geomorphological, hydrological and climatological characteristics; historical data on past natural disasters, current and forecasted extreme adverse events, as well as other specific information.

2.3 Identification of Climate-Related Hazards Affecting of the Monitored Business

Identification of climate hazards for the specific geographical region that affect the vulnerability of monitored businesses. In recent years, representative climate hazards for business companies are as follows:

- Heavy precipitation: Heavy rainfall, Heavy snowfall, Fog, Hail;
- Floods and sea level rise: Flash / Surface flood, River flood, Coastal flood, Groundwater flood, Permanent inundation;
- Extreme heat / Heat wave or Extreme cold / Cold wave;
- Droughts and water scarcity;
- Storms: Severe wind, Tornado, Cyclone (hurricane / typhoon), Tropical storm, Extratropical storm, Storm surge, Lightning / Thunderstorm;
- Wild fires: Forest fire, Land fire, *etc*.

2.4 Selection of Indicators to Characterize the Identified Climate-Related Hazards

It is assumed that each business company carefully selects experienced experts who have knowledge of both the climate-related hazards of the particular geographic region and the specifics of the company's operational activities. These experts select indicators with the appropriate measurement units for each identified climate-related hazard. These selected climate hazard-related indicators are used to determine the levels of sensitivity and exposure of the monitored business with the specific location in the certain geographical region for the given period of time.

Some of the most selected indicators to characterize the relevant identified climate hazards are as follows:

- Heavy precipitation: Frequency and intensity of extreme rainfall for a given timeframe; Number of days/nights with torrential rain/compared to the reference annual/seasonal rain per day/night in the given region for each season
- Extreme heat: Frequency and severity of heatwaves for a given timeframe; Number of days/nights with extreme temperatures (compared to the reference annual/seasonal day/night temperatures);
- Extreme cold: Number of cold days/nights, frost days/nights, snow days/nights or cold spells for a given timeframe;
- Drought: Number of consecutive days/nights without in the specified region rain for a given timeframe.

2.5 Analysis of the Sensitivity of the Monitored Business to the Identified Climate-Related Hazards

The essence of the sensitivity analysis is to assess the sensitivity levels of the monitored businesses, regardless of its location in relation to the identified climate-related hazards.

The sensitivity analysis of the monitored business comprises all constituent elements, their overall functioning, as well as their direct and indirect interrelationships with other systems in the conditions of climate-related hazards.

The assessment of the sensitivity level of the monitored businesses to the identified climate-related hazards is performed by selected experts on the basis of quantitative data, qualitative information and knowledge. The sensitivity analysis includes the following substeps:

- The variables Si, $i = 1, 2 \ldots n$ are defined, which show the "*level of sensitivity*" of the monitored business company to the climate-related hazard i, $i = 1, 2 \ldots n$ determined on the basis of expert assessment. Here the variable n indicates the number of the identified climate-related hazards.
- Five *levels of sensitivity* are defined as follows:
  - *Very high level of sensitivity* ($Si = 5$) - climate hazard i can have a very severe impact on the monitored business company;
  - *High level of sensitivity* ($Si = 4$) - climate hazard i can have a severe impact on the monitored business company;
  - *Middle level of sensitivity* ($Si = 3$) - climate hazard i can have a middle impact on the monitored business company;
  - *Low level of sensitivity* ($Si = 2$) - climate hazard i can have a low impact on the monitored business company

- *Very low level of sensitivity* (*Si* = 1) - climate hazard *i* can have a very low impact on the monitored business company.

- The experts determine the respective sensitivity level of the monitored business company for each identified climatic-related hazard.

2.6 Analysis of the Exposure of the Monitored Business Company to the Identified Climate-Related Hazards

The essence of the exposure analysis is to assess the exposure levels of the monitored business company for the specific location in relation to the identified climatic hazards, taking into account the specific characteristics of past, current and future climate conditions in the certain geographical region. Statistics and forecast estimates from specialized international databases are used, as well as data from thematic national surveys based on Geographic information systems (GIS). Such widely used databases are as follows:

- Emergency Events Database– The International Disaster Database (EM-DAT 2022);
- Climate Change Indicators Dashboard / Climate Change Data (IMF-Climate data 2022);
- Intergovernmental Panel on Climate Change (IPCC), Task Group on Data Support for Climate Change Assessments (TG-Data) (IPCC 2022b);
- European Commission - Eurostat, Database – Climate change-related statistics – Impact and adaptation (cli_iad) (European Commission - Eurostat 2022);
- World Bank - World Bank Open Data - Climate-change (World Bank 2022).

The assessment of exposure levels of the monitored business company in regards to climate-related hazards in the specific geographical region for the future climate is performed using research forecasts and simulation results from climate models that take into account potential future climate change. Such appropriate models and forecasts of climate change can be found in the following well-known sources:

- Copernicus Climate Change Service (C3S) which provides authoritative information about the past, present and future climate within the Copernicus Climate Data Store (CDS 2022);
- Coordinated Regional Climate Downscaling Experiment (CORDEX) - Global Climate Models (GCM), Regional Climate Models (RCM) and Empirical Statistical Downscaling (ESD), Regional Climate Change simulations for CORDEX domains (CORDEX 2022);
- European Environment Agency (EEA), Climate change adaptation - European Climate Adaptation Platform (Climate-ADAPT) (EEA 2022).

The assessment of the level of exposure of the monitored business company is performed by selected experts on the basis of knowledge using quantitative and qualitative data, taking into account its specificity and geographical location.

In proposed approach, the exposure analysis includes the following substeps:

- The variables *Ei*, *Epi, Eci* and *Efi, i* = 1, 2 ... *n* are defined, which show the "*Level of exposure*" (*Ei*) of the monitored business company with particular location in specific geographic region in regard to the climatic-related hazard *i*, respectively as a whole and separately for past (*p*), current (*c*) and future (*f*) conditions of climate change.
- The level of whole exposure *Ei* is defined by the following linear functional dependence

$$Ei = wpi \times Epi + wci \times Eci + wfi \times Efi \quad i = 1, 2 \ldots n$$

where $0< wpi<1$, $0< wci<1$, $0< wfi<1$ and $wpi + wci + wfi = 1$ are weight coefficients that take into account different influence of the three exposures, respectively related to the past, current and future climatic conditions to value of whole exposure. Therefore, due to climate change, it is logical to give more weight to the exposure of the current and most weight to the exposure of the future climate. That is $wfi > wci > wpi$.

- Five *levels of exposure* are defined as follows:
  - *Very high level of exposure* (*Ei, Epi, Eci and Efi* = 5) - climate hazard *i* can have a very severe impact in geographic region in which the monitored business company is located;
  - *High level of exposure* (*Ei, Epi, Eci and Efi* = 4) - climate hazard *i* can have a severe impact in geographic region in which the monitored business company is located;
  - *Middle level of exposure* (*Ei, Epi, Eci and Efi* = 3) - climate hazard *i* can have a middle impact in geographic region in which the monitored business company is located;
  - *Low level of exposure* (*Ei, Epi, Eci and Efi* = 2) - climate hazard *i* can have a low impact in geographic region in which the monitored business company is located.
  - *Very low level of exposure* (*Ei, Epi, Eci and Efi* = 1) - climate hazard *i* can have a very low impact in geographic region in which the monitored business company is located.

2.7 Determination of the Vulnerability Levels of the Monitored Business Company to the Identified Climate-Related Hazards

The determination of the vulnerability levels of the monitored business company combines the analyses of sensitivity and exposure to the identified climatic-related hazards in the specific geographical location.

In this study, the determination of the vulnerability levels includes the following substeps:

- The variables Vi, $i = 1, 2 \ldots n$ are defined, which show the "*Level of vulnerability*" of the monitored business company to the climate-related hazard i, $i = 1, 2 \ldots n$ determined on the basis of expert assessment.
- Five *levels of vulnerability* of the monitored business company to one climate-related hazard are defined as follows:
  - *Very high level of vulnerability* ($16<Vi\leq20$) - the monitored business company with its specific location is very high vulnerable to the climatic hazard i;
  - *High level of vulnerability* ($12<Vi\leq16$) - the monitored business company with its specific location is high vulnerable to the climatic hazard i;
  - *Middle level of vulnerability* ($8<Vi\leq12$) - the monitored business company with its specific location is middle vulnerable to the climatic hazard i;
  - *Low level of vulnerability* ($4<Vi\leq8$) - the monitored business company with its specific location is low vulnerable to the climatic hazard i.
  - *Very low level of vulnerability* ($1<Vi\leq4$) - the monitored business company with its specific location is low vulnerable to the climatic hazard i.
- The level value of vulnerability of the business company to the climatic hazard i is calculated as follows:

$$Vi = Si \times Ei = Si \times (wpi \times Epi + wci \times Eci + wfi \times Efi), \quad i = 1, 2 \ldots n$$

- The overall vulnerability of the monitored business company to all climate-related hazards impacting it is calculated as follows:

$$V = \sum_{i=1}^{n} V_i$$

where n is the number of climatic-related hazards impacting monitored business company.

- Five *levels of vulnerability* of the monitored business company to all identified climate-related hazards are defined as follows:
  - *Very high level of vulnerability* ($16\times n<V\leq20\times n$) - the monitored business company with its specific location is very high vulnerable to the climatic hazard i;
  - *High level of vulnerability* ($12\times n<V\leq16\times n$) - the monitored business company with its specific location is high vulnerable to the climatic hazard i;
  - *Middle level of vulnerability* ($8\times n<V\leq12\times n$) - the monitored business company with its specific location is middle vulnerable to the climatic hazard i;
  - *Low level of vulnerability* ($4\times n<V\leq8\times n$) - the monitored business company with its specific location is low vulnerable to the climatic hazard i.

- *Very low level of vulnerability* ($1\times n<V\leq 4\times n$) - the monitored business company with its specific location is low vulnerable to the climatic hazard *i*.

The higher the value of the level of vulnerability, the lower the resilience of business company to climate-related hazards. In this regard, additional analyzes of the impacts of climate hazards are being carried out, which are associated with very high levels and high levels of vulnerabilities V*i*, $i = 1, 2 \ldots n$. The probabilities of the problematic climate hazards and the severity of the respective potential consequences are analyzed. These analyzes are made so that stakeholders can make informed decisions about the choice of targeted measures to adapt monitored business company to climate change.

3. APPLICATIONS OF THE APPROACH FOR VULNERABILITY ANALYSIS OF BUSINESS TO CLIMATE-RELATED HAZARDS

The usefulness and peculiarities of the proposed approach for vulnerability analysis of business company to climate-related hazards are verified with several examples.

Here, the proposed approach is applied to an exemplary business company located in particular geographic location. The idea is to emphasize the application of the approach and for this reason, no specific business company is considered. For the monitored business company, the relevant climate hazards are identified, which can affect its vulnerability. The level values of the variables (sensitivity – *Si*; past *Epi*, current *Eci* and future *Efi* climate exposures) associated with these climate hazards as well as the corresponding calculated level values of the climate exposures *Ei* and vulnerabilities *Vi* are given in Table 1.

Usually, in the context of climate change, the level of exposure to a climate hazard associated with the future climate is higher than the corresponding level of exposure with respect to the current climate for the selected region. However, in rare cases, the level of exposure related to the future climate can be lower or the two exposures may be equal.

For example, the following values of the weighting coefficients can be selected to calculate the values of the "*Level of vulnerability*", *Ei* for each exemplary business in relation to climate hazard *i*: *wpi* = 0.2, *wci* = 0.3 and *wfi* = 0.5; $E_i = 0.2 \times Ec_i + 0.3 \times Ec_i + 0.5 \times Ef_i$.

Table 1. Values of the variables related to the vulnerability of the monitored business company

Climate-related hazards	*Si*	*Epi*	*Eci*	*Efi*	*Ei*	*Vi*	*Vulnerability level*
Climate hazard 1	S_1=4	Ep_1=3	Ec_1=4	Ef_1=5	E_1 = 3.6	V_1=17.2	*Very high level*
Climate hazard 2	S_2=2	Ep_2=2	Ec_2=3	Ef_2=5	E_2 = 1.6	V_2=7.6	*Low level*
Climate hazard 3	S_3=5	Ep_3=1	Ec_3=3	Ef_3=4	E_3 = 2.6	V_3=15.5	*High level*
***V* = 40.3**							***High level***

$E_1 = 0.2 \times 3 + 0.3 \times 4 + 0.5 \times 5 = 0.6 + 1.2 + 2.5 = 4.3$ $\quad V_1 = S_1 \times E_1 = 4 \times 4.3 = 17.2$

$E_2 = 0.2 \times 2 + 0.3 \times 3 + 0.5 \times 5 = 0.4 + 0.9 + 2.5 = 3.8$ $\quad V_2 = S_1 \times E_1 = 2 \times 3.8 = 7.6$

$E_3 = 0.2 \times 1 + 0.3 \times 3 + 0.5 \times 4 = 0.2 + 0.9 + 2.0 = 3.1$ $\quad V_3 = S_1 \times E_1 = 5 \times 3.1 = 15.5$

$$V = V_1 + V_2 + V_3 = 17.2 + 7.6 + 15.5 = 40.3;$$

$$V = 40.3$$

In accordance with the step 2.7 and n=3 for the condition $12 \times n < V \leq 16 \times n$ (*High level of vulnerability*) is obtained $12 \times 3 < V \leq 16 \times 3$ or $36 < V \leq 48$.

In the example considered, the calculated overall vulnerability is V=40.3. This value corresponds to *High level of vulnerability* for the monitored business company. This means that urgent and adequate measures must be taken to adapt the monitored business company as a whole to climate changes. The vulnerability of the monitored business company to the first climate-related hazard is also *Very high*, V_1=17.2. This necessitates initially taking significant measures to reduce the negative impact of the first climate-related hazard. After that, measures should also be determined to reduce the impact of the third climate-related hazard, because for the monitored business company the level of vulnerability is *High*, V_3=15.5. The vulnerability of the monitored business company to the third climate-related hazard is at a *Low level*. However, it should not be neglected and constantly monitored for negative changes.

4. CONCLUSIONS

Climate change is having a negative impact on business sustainability due to the increasing vulnerability of companies to climate-related hazards. An integrated approach is proposed to perform a vulnerability analysis of the businesses to climate-related hazards. It is assumed that the vulnerability degree of the business company depends on the respective levels of sensitivity and exposure to the specific climate hazards in the given geographical region. Five levels (Very low, Low, Middle, High, Very high) are defined for each of the considered variables (Sensitivity, Exposure, Vulnerability). The overall exposure level is calculated as a weighted sum of three variables relating to the past, current and future climate conditions. In accordance with the observed features of climate change, a greater weight is given to the exposure related

to the current and the greatest weight to the exposure related to the future climate. The proposed approach for vulnerability analysis of businesses to climate-related hazards is verified with several examples. The results obtained with the proposed approach for vulnerability analysis can be useful for decision-making by managers to improve adaptability of the business company to climate-related hazards.

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