Investigation of climate change on power line icing over Hungary

Levente Rácz[1], Dávid Szabó[1], Gábor Göcsei[1], Bálint Németh[1,2]

[1] *Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary.*
[2] *Electrostatics Ltd., Alsó Zöldmáli út 16., H-1025 Budapest, Hungary*

racz.levente@vet.bme.hu, szabo.david@vet.bme.hu, gocsei.gabor@vet.bme.hu, nemeth.balint@vet.bme.hu

Abstract— **This paper aims to examine the expected icing trends in the central part of the Carpathian Basin for 2031-2050. Data from the CORDEX database was applied with a spatial resolution according to EUR44 (~50 km). For the future projection, a daily time frame was chosen. The core of the simulations was to observe changes in wet snow and glaze incidence and visualize the trends in the average ice thickness and additional ice loads. Cases were analyzed with three different Regional Climate Models (RCM) for the reference (1981-2000) and the observed periods. The RCM's data were validated with weather station measurements operating within an existing dynamic line rating (DLR) system. The icing prediction subsystem of the same DLR system formed the background of the study. Regarding the performed simulations, a slight decrease in wet snow and glaze incidence is expected. It was also found that average ice thickness and additional load may increase in the coming decades. This might increase the risk of icing events. The presented results highlight the importance of the existing ice prediction and prevention methods for 2031-2050.**

Keywords— ***power line icing, climate change, future projections, wet snow, glaze***

I. Introduction

Electricity system operators have faced several new and existing challenges over the past decades [1]. Power line icing is one of the long-standing critical external factors that can cause significant damage to existing infrastructure. To maintain the energy supply and ensure a secure operation, the defense against the phenomenon is vital [2][3].

Fig. 1 Collapsed towers and damaged conductors since icing events in Hungary over the last decade [4][5].

The topographic conditions in Hungary are favorable to avoid massive power line icing most of the time. However, there have been several outages in the last 15 years due to ice accretion presented in Fig. 1, which significantly hampered consumers [4][5].

Several active and passive methods exist to prevent icing on transmission lines detailed in the literature [2]-[7]. One of these methods suggests applying Joule-heat to increase the phase conductors' temperature. Using Joule-heat is highly advantageous in anti-icing interventions but can also be proper for de-icing [3][8][9]. This approach is the basis of the complex dynamic line rating (DLR) system's icing prediction and anti-icing subsystem developed at the Budapest University of Technology (BME) and Economics. The core of the DLR method is to put sensors onto power lines and adjust the line rating to the changes of the weather parameters, thus gaining 20-30% extra transmission capacity [8][9]. From weather forecasts, the ice prediction subsystem can forecast the icing of transmission lines and the amount of heating current with DLR required for prevention. The developed system operates on several Hungarian and foreign transmission lines within domestic and European Union-funded projects, such as FLEXITRANSTORE [10] or FARCROSS [11]. Although existing models work well for native weather patterns, several studies have shown that icing phenomena can significantly change worldwide due to climate change [3]. Studies are available for different European territories [12][13]; however, detailed simulations were not performed for the Central European parts, especially the Carpathian Basin. This article aims to fill this gap and examine changes in icing and expected trends over the Carpathian Basin with numerical simulations. The results can help system operators prepare for the changes to maintain operational safety and security in the mid-term future up to 2050.

II. Data and Methodologies

In the center of the Carpathian Basin, field measurements and systematic icing observations are not available for the past, making it difficult to compile a reference data set for the simulations. On the other hand, field data measured from devices installed on power lines included in DLR projects can be used to validate the different future projections.

A. Applied data

The main goal of the simulations was to study the changes in icing trends over the next few decades. The reference period was 1981-2000, while the focus of the studies was 2031-2050. Data extracted from the CORDEX (Coordinated Regional Climate Downscaling Experiment) database were used for the simulations. CORDEX is a global partnership from which climate data for the future periods are available for different RCP (Representative Concentration Pathway) scenarios [14]. Three foreign Global Climate Models (GCMs) and three Regional Climate Models (RCMs) were defined, detailed in Table I.

TABLE I. DETAILS OF THE APPLIED RCM MODELS [14]

Model ID	RCM	Driving GCM	Institute
Model 1	RCA4	CanESM2	SMHI
Model 2	WRF33F	IPSL-CM5A-LR	IPSL
Model 3	RACMOE22E	ICHEC-EC-EARTH	KNMI

In the choice of models, the main goal was to see how the results of different approaches relate to each other. The applied data focused on a warming scenario called RCP8.5. This scenario is intended to reflect the case where there is no significant change in current emission trends. In terms of spatial resolution, EUR44 data were applied, with a spatial resolution of roughly 50 km. The examined area covers the territory of Hungary and Slovakia, on which a total of 100 (10x10) grid points were defined. The Slovak regions are essential for the simulation because the icing is more common in the mountains, e.g., in the High Tatras. Moreover, north-south energy imports cover a significant percentage of Hungary's electricity consumption. Hence, the icing in the Slovak areas also impacts Hungarian energy security. The time resolution of the data used was daily. The simulations set three primary parameters from CORDEX: ambient temperature, near-surface wind speed, and precipitation.

B. *Icing forecast system*

It is essential to mention that different environmental parameters result in different ice types, such as glaze, hard rime, soft rime, or even wet snow [2]. Numerous papers deal with the formation and physical parameters of the different types and their risks to the phase conductors and other structures [2][3][8].

For the simulations, an ice prediction model integrated into the DLR system developed by BME was used presented in Fig. 2. [8][15]. The model can determine whether icing occurs for a dedicated period, the type of ice formed, its thickness, and the additional mechanical load caused by itself.

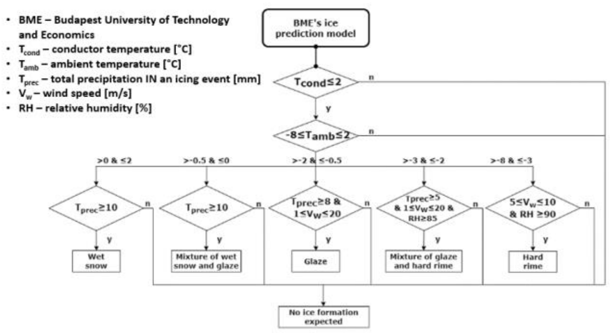

Fig. 2 Flow chart on the operation of the ice prediction system [8].

As inputs, appropriate environmental and load parameters (ambient temperature, wind speed, wind direction, relative humidity, precipitation type, precipitation intensity, and conductor temperature) are required. The model can distinguish five different icing outputs: ice formation is not expected, wet snow, a mix of wet snow and glaze, glaze, a mixture of glaze and hard rime, and hard rime. The model also includes a prefiltration that applies to the phase conductor temperature. Supposing a higher conductor temperature than 2 °C, the model does not expect any icing. The present paper focuses on the wet snow and glaze types because, in the area, these ice types cause the main problems on the transmission lines.

Suppose that icing occurs on the phase conductor; the model can estimate the thickness of the resulting ice layer and the magnitude of the additional load in two steps. For wet-snow accretion, the model follows Lacavalla et al., glaze Pytlak et al., and hard rime Saho et al. directions [16]-[19]. The resulting model proved in the previous European Union-funded FLEXITRANSTORE project that it can predict icing with high accuracy when appropriate input parameters are available [8].

III. SIMULATION RESULTS AND DISCUSSION

The simulations performed in this paper can be divided into three main parts. First, the wet snow and glaze incidence was examined in the observed (2031-2050) and the reference periods (1981-2000). The second step questioned which models can be considered relevant using the on-site weather station measurements installed on the Göd-Levice 400 kV transmission line (Fig. 3) in the European Union-funded FARCROSS project. In this step, the attributes of the 3 RCMs are also analyzed. Finally, it was discussed how the average ice thickness and the average additional load caused by icing might change in the different periods.

Fig. 3 Weather station installed onto the Göd-Levice 400 kV power line [11].

During the work, the scope of the simulations was on the changing trends. Thus, some assumptions were made that may affect the simulation results. The conductor temperature was set to 0 °C in each case to increase the possibility of icing. The wind direction was taken as a fixed 90 degrees in each case, which worked as a worst-case scenario. Regarding the relative humidity, several independent issues were examined, and it was found that simulating random values from the 60 and 95% ranges did not significantly affect the results. In the space between the grid points, linear interpolation was used for better visualization.

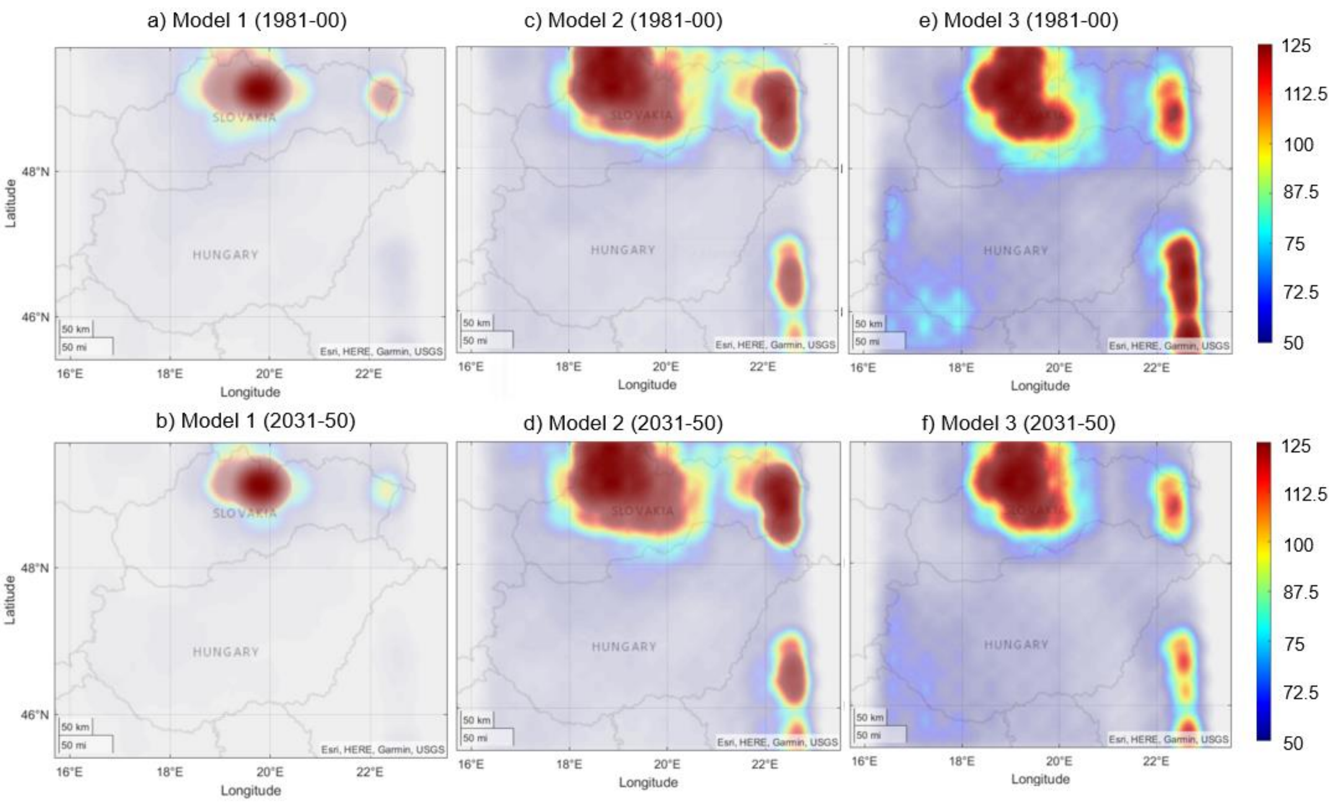

Fig. 4 Simulated wet snow and glaze coincidence (number of icing days [-]) for (1981-2000) and (2031-2050) based on the three RCMs.

A. *Simulation of wet snow and glaze incidence*

Fig. 4 represents wet snow and glaze incidence during the observed periods. Given that the simulations were performed with daily data, the results equal the number of icing days occurring in a given period. The figure shows that the results of all three models correlate with the geographical conditions of the study area. The frequency of icing days is significant in the ranges of the North-Western Carpathians, especially in the High Tatras. In addition, many ice formation is seen at the north-eastern part of the grid points, marking the beginning of the North-Eastern Carpathians. The third major icing hotspot is at the southwestern part of the map, where the Apuseni Mountains and the Southern Carpathians are located. At the same time, it is essential to mention that there is still a significant cluster in the western and southwestern parts of Hungary in the case of the third model. It is worth noting that no intense icing can be seen in Hungary. However, former studies showed that heavy wind and smaller ice loads could significantly damage this region [4]. The main difference between the three simulation results is the extent of the areas indicated by intense icing; the first model predicts the lightest scenario, while the third model predicts the riskiest one. Based on the simulations, it can be said that for the two ice types studied, a slight decrease is expected in the coming decades based on Model 1 and Model 3, while Model 2 shows a slight increase in the current icing trends. Based on the results, no change in the spatial distribution of icing is expected.

B. *Comparison of RCMs and field measurement*

Given that the three models show different results and trends, it was examined how the weather parameters simulated by the models are related to the field measurements.

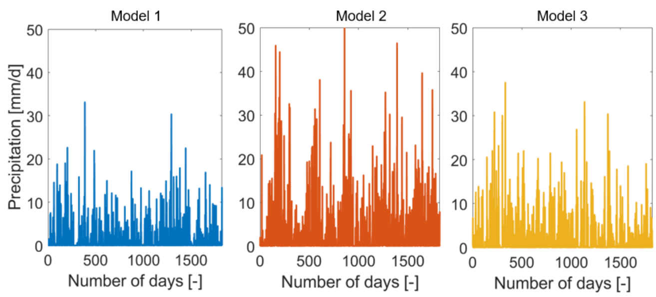

Fig. 5 Simulated precipitation from the applied models for a 5-year period.

Fig. 5 presents how the precipitation simulated from the three RCM varies over the used grid points for five years. Model 2 provides the highest precipitation rate based on the figure, while Model 1 calculates the lowest. The simulated wind speed values are in the same ranges.

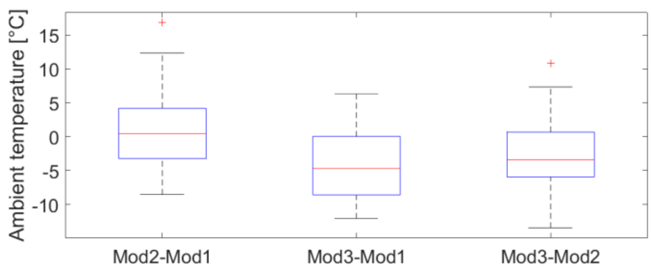

Fig. 6 Boxplot diagrams presenting the difference in an ambient temperature between models for a 5-year period.

Fig. 6 shows the difference between the models in terms of ambient temperature. It can be seen from the figure that there are significant differences between the RCM models - Model 1 and Model 2 predict lower temperatures by approximately

5 °C. The properties of RCMs are well reflected in the first simulation results in Fig. 4. It can be seen that the more intense precipitation predicted by Model 2 and the lower temperature projected by Model 3 indicated a more intense icing process.

To compare the simulated and field results, one of the grid points was defined to cover the point on the Göd-Levice transmission line where a weather station is mounted on a high voltage tower. Comparing the results of the models and the actual measurements for the year 2021, it was observed that there is no significant difference in terms of ambient temperature and wind speed; however, this can no longer be said in terms of precipitation.

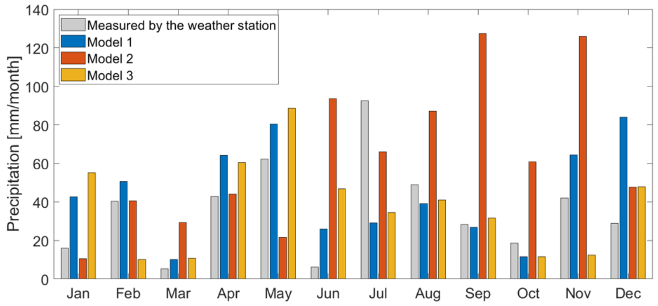

Fig. 7 Monthly precipitation rate from the models and the field measurement.

Fig. 7 shows the differences between the simulated precipitation of the three models and the measured precipitation in a monthly breakdown. Model 2 significantly overestimates the annual precipitation (754 mm) regarding the measured value (432 mm), and the interannual distribution does not follow the trends either. In contrast, Model 1 provides a more accurate estimate (528 mm), while Model 3 provides annual precipitation with little uncertainty (450 mm). Based on these, Model 1 and Model 3 seem to be closer to the actual conditions, so only their results are presented in the later parts.

C. Changes in ice thickness and additional ice loads

The next step was to simulate how the average ice thickness changes in wet snow and glaze formations compared to the reference period. Since ice formation is not independent of the structure's physical properties, an ACSR 500/65 mm^2 conductor was chosen for these investigations. This conductor type is common in the Hungarian 400 kV transmission network. The properties of the conductor are explained in Table II.

TABLE II. DETAILS OF THE APPLIED CONDUCTOR

Parameter	Value	Measuring unit
No. of Al strands	54	-
No. of Steel strands	7	-
Strand diameter	3.45	mm
Outer diameter	31.06	mm
Specific weight	1.94	kg/m

During the simulations, the ice thicknesses were summed to the given period and divided by the number of icing days.

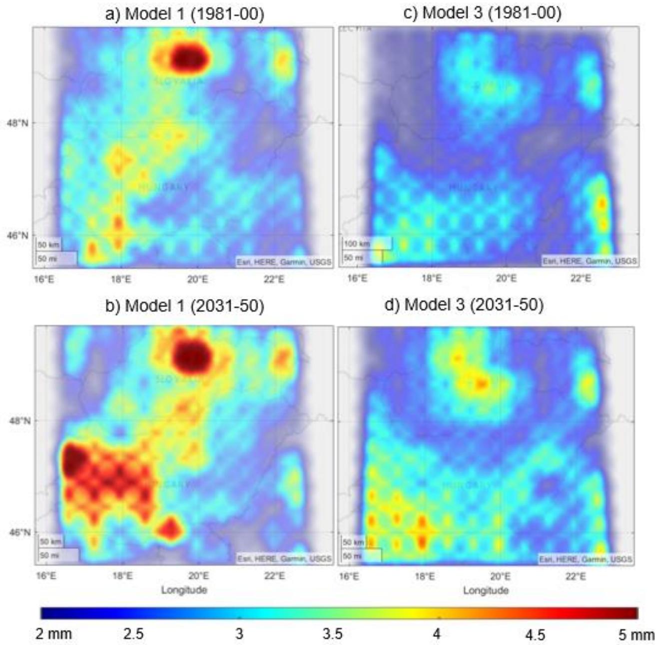

Fig. 8 Change in average ice thickness between (1981-2000) and (2031-2050) based on Models 1 and 3.

Based on the results of Model 1 and Model 3, the ice layer of the mentioned icing types can reach even 5 mm on average in Hungary. The simulations for both models indicate that the average ice thickness may increase in some parts of the region, especially in the western parts of Hungary. In those areas, 2 mm ice layer increment seems possible on average based on the RCM inputs. Based on the performed simulations, the frequency of wet snow and glaze occurrence decreases between (1981-2000) and (2031-2050) as shown in Fig. 4, but the intensity of these events increases, leading to increased ice thickness, as shown in Fig. 8. A possible explanation for these results can be the more common presence of extreme weather conditions due to climate change, resulting in fewer icing days, but on these days, greater ice thickness on the phase conductors.

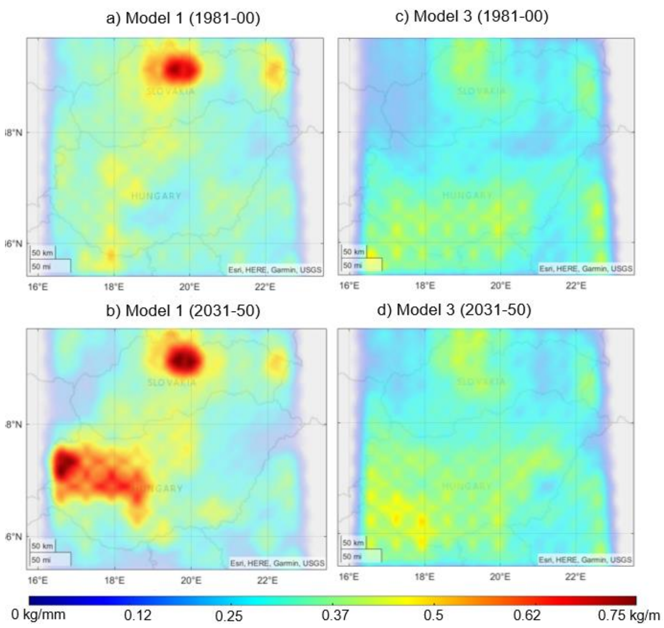

Fig. 9 Change in average additional ice loads between (1981-2000) and (2031-2050) based on Models 1 and 3.

After examining the ice thickness, the amount of additional load from the ice layer was simulated [16]-[19]. For this case, the change in the average values for Model 1 and Model 3 is presented in Fig. 9. According to Model 1, in the case of Hungary, the average additional load increase is mainly in the western part of the country. In the case of Slovakia, the average mechanical load may increase in the High Tatras region, where high voltage power lines are not frequent. Model 3 also projects higher average ice loads in several areas, mainly in Hungary's southern and western parts. The results for Model 1 and Model 3 are broadly similar in terms of average ice thickness and average additional load. There may be an explanation for this, that on the examined grid density, the proportions of wet snow and glaze will not change significantly in the coming decades.

D. Key findings and future plans

Based on the presented work, several initial conclusions can be drawn regarding the icing trends and RCMs in the region. These are the followings:

- Model 1 and Model 2 results correlate well with the field measurement of the weather station installed in the DLR project.
- In the case of Model 2, the amount and interannual distribution of precipitation simulations do not seem realistic, so the results of this model should be treated with caution.
- The performed simulations (with the presented boundary conditions and model simplifications) project that the frequency of wet snow and glaze in the Carpathian Basin is expected to decrease.
- While the incidences decrease, neither the expected average ice thickness nor the average additional load in the area decreases according to the studied models. These findings appear to be significant mainly for the central region of Slovakia and the western part of Hungary.
- One explanation for ice thickness may be that fewer but more dangerous icing phenomena are expected in the coming decades.
- The coordinated use of icing prevention and forecasting systems can continue to play an essential role in the region.

Although the results serve as a good starting point, it is essential to note that the simulations presented here made assumptions. Plans include reducing these assumptions by examining more RCMs, defining denser grid points, and more detailed temporal resolution. A more accurate examination of the conductor temperature can also help to filter out false alarms. Finally, additional parameters can also help get a more accurate picture of the future of icing trends in the region and Hungary.

IV. Conclusions

The presented paper examined how the icing trends in the central parts of the Carpathian Basin will change by 2050. CORDEX data with three RCM models were used for the simulations; the focus was on the change in the incidence of wet snow and glaze and the change in average ice thickness and additional load. The three models gave similar results but different changing trends. Thus, data of a weather station installed during an existing DLR system was used as a reference. Regarding precipitation, we found anomalies in the case of Model 2, based on which we did not investigate that model further. For Model 1 and Model 3, the experience was that there could be a slight decrease in the incidence of icing in the region. On the other hand, in some areas, especially in the western part of Hungary and in the middle of Slovakia, the average ice thickness and the additional load caused by itself may increase. One possible explanation for this phenomenon can be less frequent but more intense icing due to more extreme weather conditions in the future. Although, based on the results shown, using icing prediction and prevention systems remains necessary in the following decades, further simulations and refinements are needed to have a more resounding conclusion on this topic.

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