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Spatially distributed assessment of solar resources for energy applications in Slovakia

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Abstract: Spatial and temporal distribution of available solar energy depends on several factors. Besides latitude and astronomical factors it is strongly influenced by climate factors (e.g. cloudiness, turbidity) and topography. This paper presents a solar database of Slovakia containing spatially-distributed solar energy resource data necessary for planning, sitting and forecasting of solar device installations. The database consists of several data sets showing monthly and annual real-sky and clear-sky irradiation on horizontal and optimally-inclined planes. It was derived from available solar radiation databases, ground-station meteorological data, digital elevation model with a horizontal resolution of 100 m and methodology based on the r.sun solar radiation model. The analysis and modeling was performed within the open-source environment of GRASS GIS. The results show that an average daily sum of real-sky solar irradiation on a horizontal plane is about 3.0 kWh/m^2/day (ranging from 2.7 to 3.3 kWh/m^2/day for 95% of the area) with the highest potential in southern areas of the Slovak territory. Northern, mountainous areas have a mixed potential that strongly depends on local topography (areas affected by shadows). The energy yield can be increased by optimization of solar panel inclination. The solar panel inclined to 34-46 degrees receive about 2.9-3.8 kWh/m^2/day of solar irradiation (95% of the area) with the average value of 3.3 kWh/m^2/day. The study showed a strong seasonal variation of available solar energy with the highest values during summer months. Horizontal planes in December, in average, receive only 15% of solar irradiation available in June. The optimization of solar panel inclination increases the availability of solar energy during winter up to 30% of June values.

Key words: solar radiation, irradiation, renewable energy, geographic information system, Slovakia

Introduction

Solar energy is one of renewable energies (RE) with a rapidly growing importance. In these times, this fact is even more boosted by environmental costs and limited supply of fossil fuels, progress in solar technology with an increasing efficiency of solar energy conversion (Jäger-Waldau, 2005). Solar energy is currently used in a number of applications that can be grouped in three major areas: heat production (hot water, building heat, cooking), electricity production (photovoltaics) and desalination of seawater.

While the amount of solar radiation on the Earth's upper atmosphere is almost constant (1366 W/m^2), the availability of solar irradiation on the Earth's surface is greatly spatially and temporally variable. The key factor is latitude with the greatest available irradiation in tropics and the lowest values around the poles. The seasonal dynamics of irradiation is given by astronomic factors. The atmosphere absorbs and reflects large part of the radiation, so the irradiation in desert areas near tropics is about 7 to 9 kWh/m²/day.

The varying atmospheric conditions (clouds, dust, pollutants) further modify the availability of solar irradiation within years and even days. Atmospheric conditions not only reduce the quantity of insolation reaching the earth's surface but also affect the insolation quality by scattering and absorption of incoming light and altering its spectrum. While average insolation data offer an insight into solar energy potential on a regional scale, locally relevant conditions such as surrounding terrain may significantly influence the solar energy potential in a specific site.

Solar systems (photovoltaics, heating and cooling systems) are experiencing a rapid growth (Jäger-Waldau, 2005), and more detailed knowledge of the primary solar energy resource is needed. Clearly, the analysis of available solar energy resources is part of the efforts to integrate solar energy into energy systems in many countries. For example, Šúri et al. (2006) present a complex database of solar irradiation maps and other climatic parameters for Europe. New web-based tools were developed to provide an access to the database and make assessments of the photovoltaic systems performance (Šúri et al., 2005).

The improved knowledge can significantly contribute to a better siting and economic assessment of new installations and improve the performance monitoring and forecasting. It is also needed for a large-scale integration of solar energy systems into existing energy and economic structures. The geographical factors, spatial and temporal distribution of renewable energy resources impose questions that also require specific location-dependent answers in policy making. Therefore a map-based assessment of available solar resources greatly contributes to the effective policies to be set at the level of the European Union, its member states and regions (Šúri et al, 2006).

In Slovakia, several authors studied solar radiation and its components including methodology issues and factors affecting its spatial and temporal variability (e.g., Kitler and Mikler (1986), Hrvoľ (1996), Hrvoľ and Horecká (2000), Krcho (1990), Jenčo (1992), Hofierka (1997)). The spatial variability of global irradiation in the territory of Slovakia was analyzed by various methods. For example, Hrvoľ and Tomlain (1992, 1997), Tomlain and Hrvoľ (2002) published maps of global irradiation for horizontal and inclined planes developed using meteorological data containing monthly averages of cloudiness and relative sunshine duration from the time periods of 1951-1980 and 1961-1990. The maps of global irradiation were derived by manual interpolation. Šúri (2002) presents a 500-m database of global irradiation derived using the *r.sun* model, digital terrain model (DTM), meteorological data taken from the SODA website and data published by Tomlain and Hrvoľ (1992). This database was further analyzed to assess the photovoltaic potential of urban areas in Slovakia (Šúri et al., 2002) and electricity yield potential for different types of photovoltaic system installations (Šúri 2006).

To account for spatial variations of solar irradiation in different geographical conditions, solar radiation models integrated with geographical information systems (GIS) were developed. Solar radiation models use ground-based or satellite data and DTMs as inputs into physically-based and empirical equations to provide estimates of irradiation over large regions, while considering terrain inclination, orientation and potentially also shadowing effects. In our previous work (Šúri and Hofierka, 2004), we have analyzed GIS-based solar radiation models, such as *SolarFlux* (Dubayah and Rich, 1995, Hetrick et al., 1993), *Solei* (Mészároš, 1998), *Solar Analyst* (Fu and Rich, 2000) and *SRAD* (Wilson and Gallant, 2000). An analysis showed that these models have some restrictions in terms of their applicability in large regions and handling all necessary input parameters as spatially-distributed data. Hofierka (1997) has developed a clear-sky solar irradiation model *r.sun* implemented in an open-source environment of GRASS GIS. This model has been further improved by Šúri and Hofierka (2004) to include diffuse and reflected components of solar radiation for clear-sky and real-sky modeling. The model is sufficiently robust and flexible over various scales. Therefore we decided to use the *r.sun* model in the analysis of the solar energy resources in Slovakia.

The aim of this study is to assess solar energy resources in Slovakia at a regional scale represented by 100-m horizontal resolution of raster-based GIS data. The dynamics of solar energy resources is analyzed on a monthly basis. Local optimization of solar panel inclination is analyzed in order to maximize the potential annual energy yield. The regional analysis and implications for regional development and possible support schemes is based on NUTS-4 level represented by 79 Slovak districts.

Methods and data

The r.sun solar radiation model

Šúri and Hofierka (2004) have developed a comprehensive GIS-based methodology for computation of solar irradiation and irradiance for any geographical region and for any time moment or interval. This solar radiation methodology has been implemented in the *r.sun* module of GRASS GIS (Neteler and Mitasova, 2004). The *r.sun* model has the following key features:

- It is a raster-based GIS program with spatially variable input and output data. Alternatively, selected parameters can be set as constants.
- It is an open source model with available source code for further improvement.
- Provides all components of clear-sky and real-sky solar radiation for irradiation and irradiance values.
- Calculation can be performed assuming solar or civil time.

- It has a large scalability for various spatial resolutions and region sizes. Memory management and code optimization allows to use high resolution data.
- Integration with the open-source environment of GRASS GIS provides another GIS tools for processing input and output data directly within one computing environment.

The *r.sun* model is based on the methodology that uses equations published in the European Solar Radiation Atlas (Scharmer a Greif, 2000). It estimates beam, diffuse and reflected components of clear-sky radiation taking into account attenuation of extraterrestrial radiation by air-mass and atmosphere turbidity. The real-sky radiation is approximated from clear-sky radiation using clear-sky index representing the attenuation of clear-sky radiation by cloudiness. The map of clear-sky index is usually derived from ground measurements by interpolation or from satellite data. The calculation of irradiation on inclined planes requires the estimation of direct and diffuse components of global horizontal radiation. Similarly to clear-sky index, the ratio of diffuse and global radiation can be derived using ground-based data and spatial interpolation or models based on satellite data.

The *r.sun* model works in two modes. In *mode 1* for the instant time, it calculates raster-based maps of solar irradiance ($W.m^{-2}$) and solar incident angle (degrees). In *mode 2*, the raster-based maps of daily sum of solar irradiation ($Wh.m^{-2}$) and duration of the beam irradiation (minutes) are computed from the integration of irradiance values that are calculated at a user-selected time step from sunrise to sunset. If selected, the computation can account for sky obstruction (shadowing) by local terrain features.

By shell-scripting within the Linux operating system environment, these two modes can be used separately or in combination to provide estimates for any desired time step or interval. A theoretical background and possible applications are described in papers by Šúri and Hofierka (2004) and Šúri et al. (2005). Synopsis, description and notes to the command can be consulted in the book by Neteler and Mitasova (2004) and manual page for the *r.sun* module (GRASS 2007).

Recently, the *r.sun* module has been supplemented by another modules based on this methodology that help prepare spatially-distributed solar databases (Šúri et al., 2007). For example, *r.sunyear* calculates the optimal inclination of south oriented planes in order to maximize daily or annual irradiation input with 1°-precision. The module provides the optimized inclination of the plane as well as corresponding global irradiation values including direct, diffuse and reflected components.

The most computationally demanding part of the methodology is the analysis of terrain shadows. The internal procedure of the *r.sun* module can be used or, alternatively, a separate calculation of horizon angles using the *r.horizon* module can be used to speed-up the calculation for large grids. The output of this module is a grid/raster representing angles between horizontal plane and terrain horizon for a specified direction. Series of such grids describing horizon angles for all directions (with a specified step, usually 3.75° – 15°) can be then used as an input to the *r.sun* module simplifying its internal procedure. The *r.horizon* module as well as the internal shadowing algorithm of the *r.sun* module take into account a curvature of the Earth and angular distortions caused by cartographic projections.

Input data

The input data in our study were prepared using existing data sources that were analyzed and processed in the form required by the *r.sun* and other solar radiation modules in GRASS GIS. These include DTM, measured global and diffuse solar irradiation from ground stations and a map of Linke turbidity coefficient.

One of key factors affecting the available solar energy is elevation and terrain features. Elevation determines the attenuation of radiation by optical thickness of the atmosphere (air mass). Slope (inclination) and aspect of terrain modify the incident beam, diffuse and ground-reflected radiation components. In solar energy applications the influence of the slope and aspect is sometimes less evident, as the panels are usually mounted with orientation and inclination maximizing the energy yield, regardless of the local terrain. On the other hand, the neighboring terrain features can considerably change the irradiation patterns in mountains via shadows and visible fraction of the sky. They play an important role especially at low Sun altitudes (in Slovakia during a winter season) and sunrise/sunset times, when even a relatively small terrain feature can present an obstacle for direct solar radiation. Thus the influence of shadows is more pronounced under clear-sky (sunny) weather than overcast (cloudy) conditions when a diffuse component of radiation dominates. The terrain also influences the cloudiness and aerosols distribution and thus indirectly influences the amount of available solar energy.

In a GIS, terrain is represented by a DTM. A horizontal resolution of raster-based DTMs significantly affects the accuracy of modeling and spatial patterns of solar irradiation. The shadows cast by surrounding terrain features are the most sensitive to the resolution. The DTM used in our study is based on the STRM data acquired by spaceshuttle Endeavour mission in 2001 by C-band SAR interferometry instrument (Zyl 2001). These data cover approximately 80% of total Earth surface. In the northern hemisphere the data cover the area up to 60 degrees of north latitude. The original resolution of the data is 1 arcsec and for areas outside the US the 3-arcsec data are freely available that represent approximately a 90-m resolution. The accuracy of 1-arcsec data for the European continent is represented by absolute horizontal error of 8.8 m and absolute vertical error of 6.2 m in 90% of this area (Rodriguez et al. 2006). The available 3-arcsec data in the WGS84 geographic coordinate system were reprojected and resampled to 100-m resolution. The processed 3-arcsec SRTM data present a DTM used in this study (Fig.1). To take into account the shadowing effects of surrounding terrain, a 50-km strip of DTM behind the state border of Slovakia was also included in the analyses. The analysis of shadows on large grids for every day throughout the year means very high computing demands that can be minimized by the *r.horizon* module. A set of 96 data layers representing horizon angles with direction angle step of 3.75° were pre-computed using this module to avoid a slower internal shadowing algorithm and speed-up the calculation in the *r.sun* module.

The ground meteorological stations measuring solar irradiation and other related meteorological parameters (e.g. turbidity, cloudiness, etc.) are usually sparse and heterogeneously located and in most cases they do not represent spatial and vertical variability of solar irradiation adequately. In Slovakia, only 6 meteorological stations with direct measurements of global solar irradiation were available. To use the maximum of available information, these stations have been supplemented by another 16 close-to-border meteorological stations in the neighboring countries totalling to 22 stations used in this study (Fig. 1). The measurement of global and diffuse solar irradiation is needed to assess the ratio of real-sky and clear-sky radiation represented by clear-sky index and its direct and diffuse components used to derive real-sky irradiation on inclined planes (Šúri and Hofierka, 2004). The clear-sky irradiation can be relatively easily computed using the *r.sun* model, however, real-sky irradiation is more dependent on local meteorological conditions (cloudiness) that reduce the amount of available irradiation for energy applications.

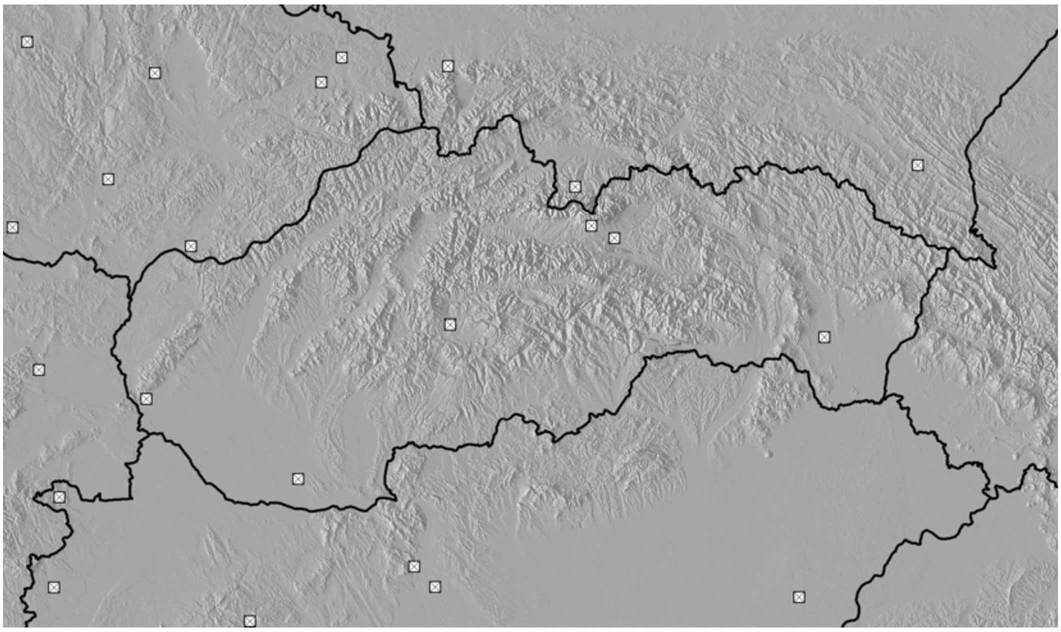

Fig. 1. *Ground meteorological stations with measured solar irradiation and DTM derived from SRTM data*

To prepare spatially-distributed input data (raster-based maps) derived from measurements, interpolation techniques are frequently used, such as splines, weighted averages or kriging (see Hutchinson et al., 1984; Hulme et al., 1995; Zelenka et al., 1992). However, low spatial density of meteorological stations measuring solar irradiation still requires a sophisticated interpolation approach, such as co-kriging (D'Agostino and Zelenka, 1992; Beyer et al., 1997) or multivariate splines (Hofierka et al., 2002, Šúri and Hofierka, 2004), in order to include additional variable (information) from DTMs or satellite images and improve the quality of interpolation. Using this approach, Šúri et al. (2005) have prepared a comprehensive set of various solar irradiation data including the *r.sun* input parameters for Europe that also covers the territory of Slovakia. These data were prepared including the measurements from 22 meteorological stations used in this study. However, a horizontal resolution of these data is 1 km. Therefore the original grid maps were resampled to 100-m resolution used in this study. The resampling was done using spatial interpolation with smoothing that better adopt the original data represented by grid points to a new resolution and minimize the abrupt changes in data. The resolution of 100 m is sufficient with respect to data density of meteorological data and spatial variability of terrain. The transformation was done for beam and diffuse clear-sky index components and Linke turbidity grid maps.

The Linke turbidity maps were originally derived from a global database published by Remund et al. (2003) with the original horizontal resolution of 5' that has been further enhanced to 1-km resolution using the reverse altitude correction and interpolation to match the 1-km DTM variability (Šúri, personal communication).

The beam and diffuse clear-sky index components were derived from monthly averages of meteorological stations measurements of global and diffuse radiation for the 1981-1990 period (Scharmer a Greif, 2000) and clear-sky global irradiation computed using the *r.sun* model (Šúri et al. 2005). The monthly averages of clear-sky index values and ratio of diffuse and global irradiation were interpolated using the *s.vol.rst* module in GRASS GIS containing a tri-variate version of Regularized Spline with Tension (Neteler and Mitasova 2004). As a third, additional variable enhancing the resolution and accuracy of interpolation was used elevation represented by 100-m DTM. Finally, raster -based maps of beam and diffuse irradiation components and clear-sky index required by the *r.sun* model for estimation of real-sky irradiation on inclined planes were derived.

The calculation procedure

The solar database represented by final maps in Figs. 3-6 was computed by the *r.sun* module and above mentioned GRASS GIS modules in these three major steps (Šúri and Hofierka, 2004):

1 Computation of global clear-sky irradiation on a horizontal plane;

2. Calculation of global real-sky irradiation on a horizontal plane and its direct and diffuse components using the beam and diffuse clear-sky index components;

3. Computation of the optimal inclination of the southward-oriented plane to maximize the annual irradiation yield using the *r.sunyear* module and computation of irradiation impinging on optimally-inclined planes.

All databases were derived as spatially distributed raster-based maps representing monthly and annual averages of daily sums of irradiation in kWh/m^2/day. For regional analysis and possible supporting schemes the raster-based maps were averaged for spatial administrative units at the NUTS-4 level.

Results and discussion

The application of the above mentioned methodology and data have led to creation of a set of raster -based maps with a horizontal resolution of 100 m representing a solar database that can be effectively used for solar energy applications. The database consists of twelve monthly averages and one annual average of daily sums of global irradiation on a horizontal plane under real-sky and clear-sky conditions, spatially-distributed values of optimum inclination angle of a plane (e.g. solar panel) to maximize annual energy yield from solar devices and monthly averages of real-sky global irradiation for optimally-inclined planes. Besides these final data, several raster-based maps that were used in the computation are also available (beam, diffuse, reflected components of global irradiation, Linke turbidity, ratio of diffuse and global irradiation on a horizontal plane, ratio of global irradiation on optimally-inclined and horizontal planes, digital terrain model, etc.).

The quality of the model outputs reflects the source data and solar radiation methodology. A high-resolution DTM improved the accuracy of topography factors (relative air mass and shadowing). The real-sky irradiation modeling is more influenced by the lack of representative ground-based measurements reflecting local variations and dynamics of cloudiness. The ground-based measurements were spatially enhanced using a sophisticated tri-variate interpolation method that helped to reflect the local variability of irradiation due to topography. The overall accuracy of the database represented by monthly and annual values of irradiation was assessed using basic statistical measures, the relative mean bias error (rMBE) and relative root mean squared error (rRMSE). The rMBE in 6 evaluated meteostations in Slovakia reached 3.1% and 2.7% for monthly and annual real-sky irradiation on a horizontal plane, respectively. The rRMSE for monthly and annual irradiation was a bit higher approaching 5.9% and 4.2%, respectively.

The first set of solar resource maps is focused on available clear-sky and real-sky irradiation on a horizontal plane. Solar irradiation on ground-based stations is measured for horizontal planes, so these predictions can be directly compared to measured solar irradiation data. Also, some solar energy devices may need to be installed on horizontal planes, so these maps can be used as a basis for energy generation assessment from a solar system.

The clear-sky global solar irradiation (Fig. 2a-c) presents global irradiation without the influence of cloudiness (sunny conditions). Effectivelly, it is a maximal irradiation that can be received by the Earth surface without the influence of cloudiness. The clear-sky irradiation, however, contains the influence of turbidity caused by various aerosols in the atmosphere. The clear-sky irradiation maps were computed by the *r.sun* module using DTM, Linke turbidity maps and constant albedo 0.15. The general latitudinal pattern is significantly influenced by topography throughout the year. In December (Fig 2c), however, the shadowing effect of terrain in mountainous areas plays a more important role thus reducing the amount of available solar irradiation in valleys and northern slopes. The maximum values of daily sums of average clear-sky irradiation in June are up to 8.7 kWh/m^2/day, in December the amount is reduced to 1.0-1.5 kWh/m^2/day, locally even less. The annual sums of clear-sky irradiation on a horizontal plane are within the interval of 1500-1800 kWh/m^2/year.

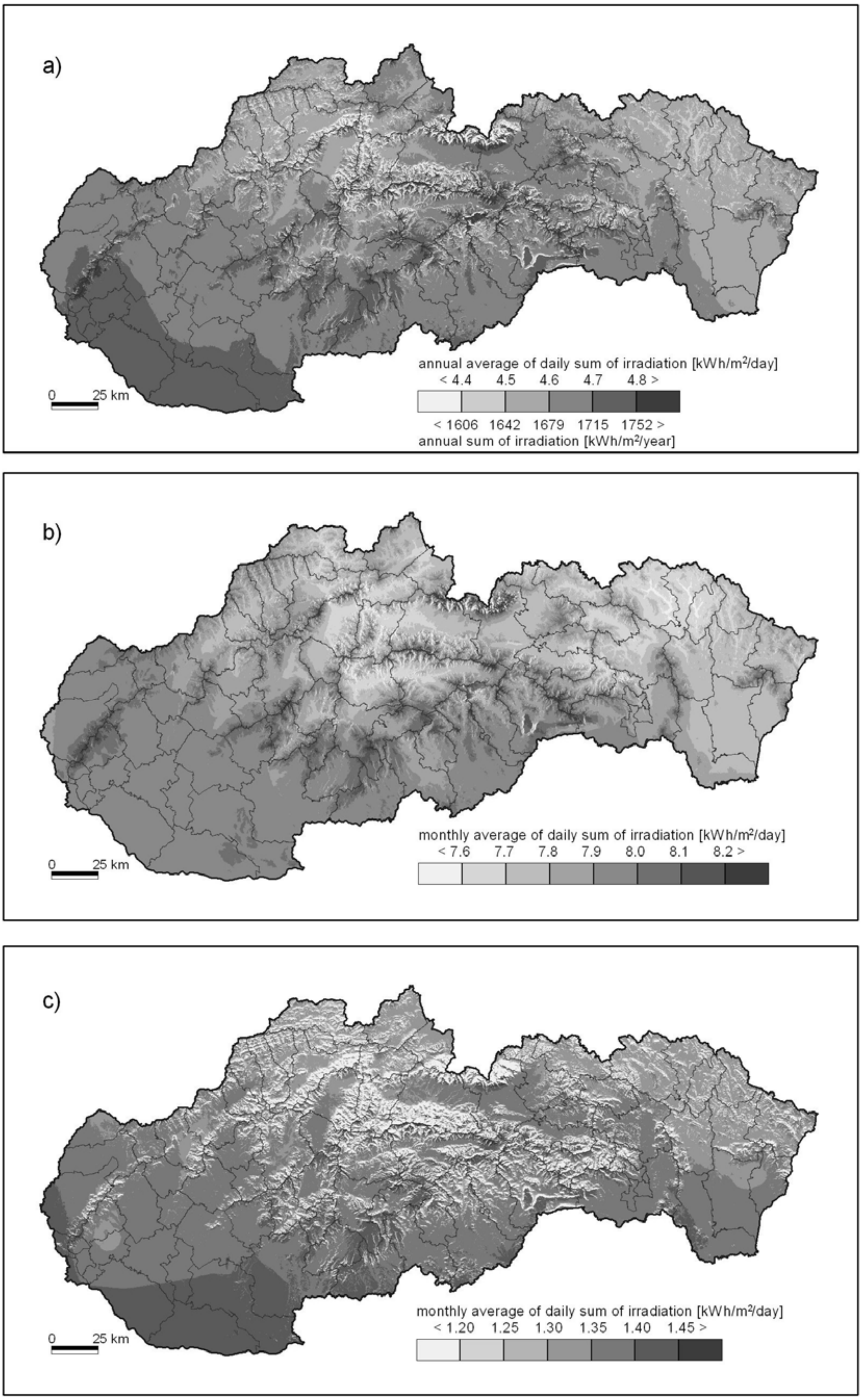

Fig. 2. *Annual (a), June (b), and December (c) daily average of global clear-sky irradiation on a horizontal plane*

Fig. 3a shows daily sums of annual average of global real-sky irradiation (in kWh/m^2/day) incident on a horizontal plane, Fig 3b and Fig 3c show a monthly average for June and December, respectively. The general latitudinal pattern is, similarly to the clear-sky irradiation, influenced by local topography and climate conditions with higher values in the south-west (up to 3.3 kWh/m^2/day) and lower values in the north (about 2.7 kWh/m^2/day). The average annual value for the territory is about 3.0 kWh/m^2/day. The annual sums of real-sky irradiation on a horizontal plane are within the interval of 900-1200 kWh/m^2/year. However, the general trend is substantially modified by topography in mountainous areas. Therefore the values of annual average of real-sky global irradiation locally fluctuate with an increase on southern slopes and decrease on northern slopes and very strong decreases in valleys caused by topographic shadows.

Even more striking is the comparison of summer (June) and winter (December) conditions (Fig. 3b vs. Fig. 3c). In December, the amount of available solar irradiation is only 15% of the amount available in June. Also it is clear that during winter the amount of real-sky irradiation in Slovakia is more dependent on local climate and terrain conditions and less on latitude. Low sun altitudes during winters increase the influence of shadows in mountainous areas.

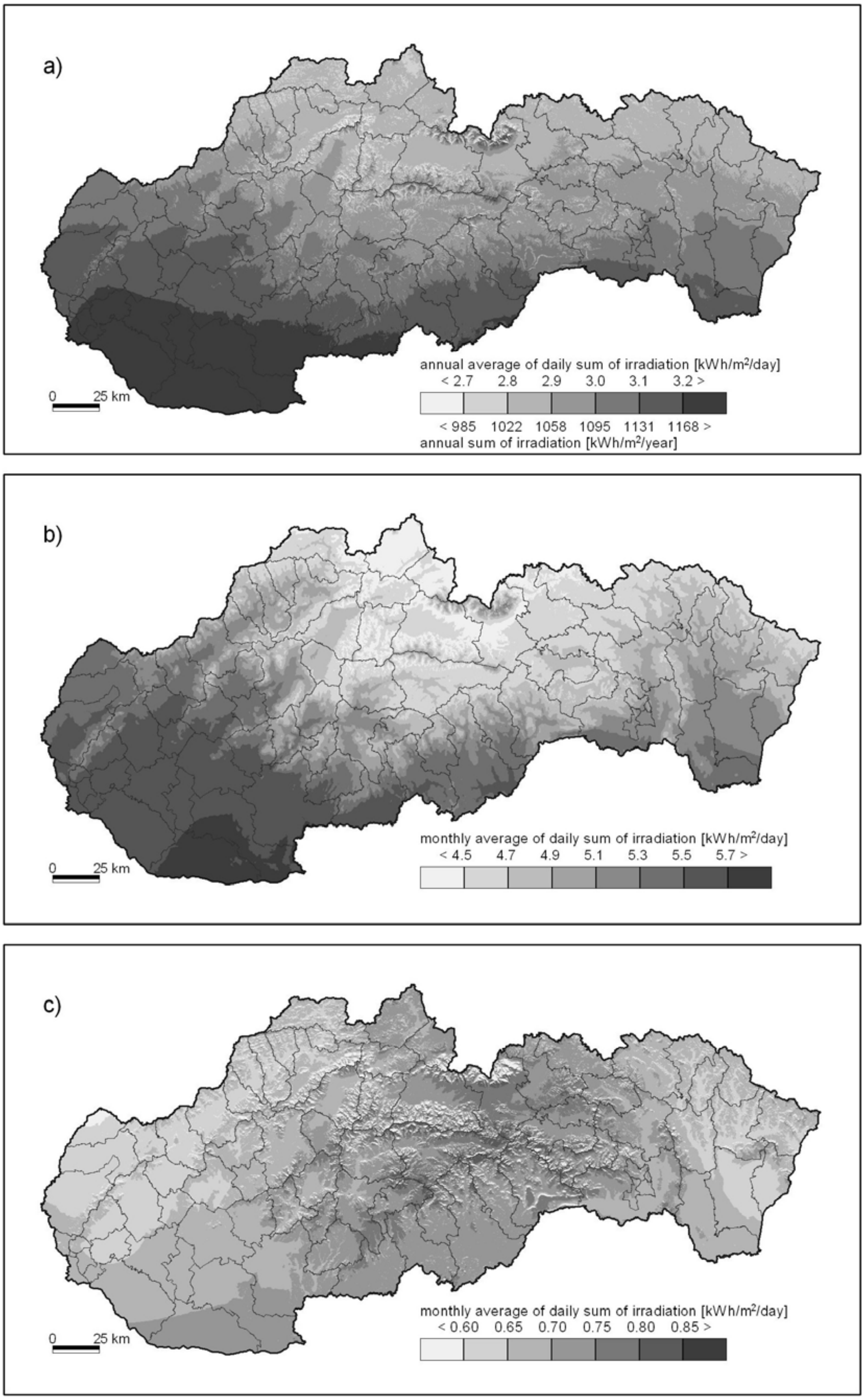

Fig. 3. *Annual (a), June (b), and December (c) daily average of global real-sky irradiation on a horizontal plane*

Slovakia lies in middle latitudes, so it is reasonable to consider the inclination of solar panels in order to increase the irradiation input. In Fig. 4, the optimized values of solar panel inclination are presented to maximize solar energy yield throughout the year. Most areas are in the range of 34 to 46 degrees. The optimization of solar panel inclination leads to a slight increase in daily sums of annual average of global real-sky irradiation received by solar panels (2.9-4.0 kWh/m^2/day). The total sum of annual irradiation increased, in average, by 14% compared to horizontal irradiation. The optimization helps especially during winter months when the amount of solar irradiation is low and it is important to capture the maximum of available irradiation (Fig. 5a-c). In December, the amount of solar irradiation received by solar panels is about 30% of summer values (1.0-1.5 kWh/m^2/day).

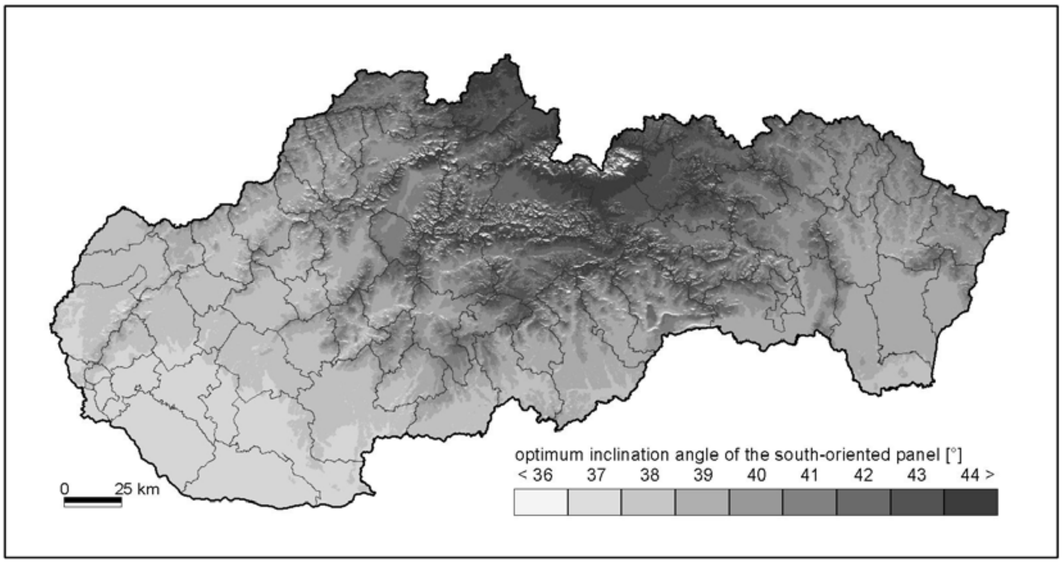

Fig. 4. *Optimized inclination of a south-oriented plane to maximize annual energy yield*

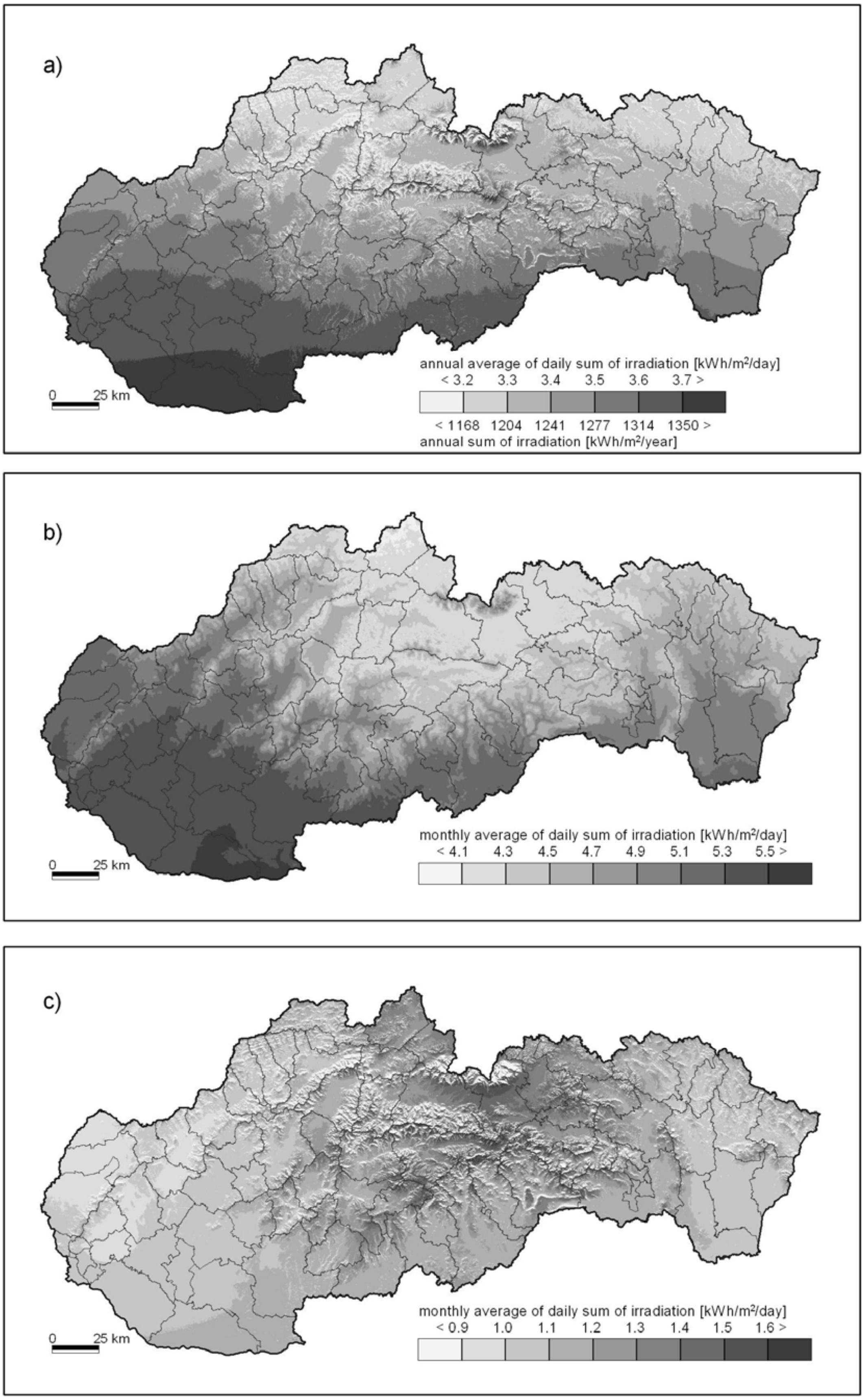

Fig. 5. *Annual (a), June (b), and December (c) daily average of global real-sky irradiation on a optimally inclined plane*

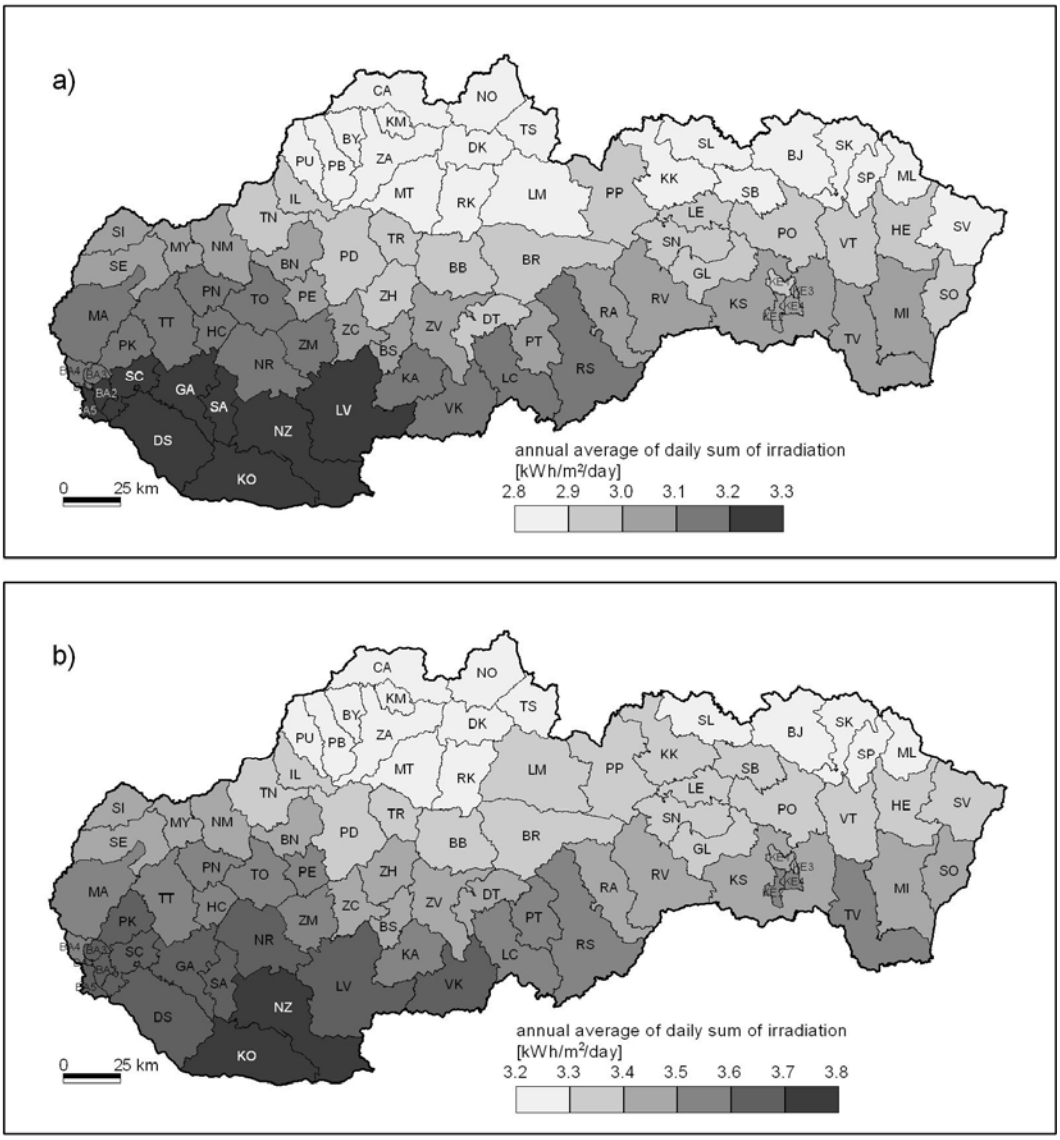

Fig. 6. *Regional variability of available solar energy a) horizontal plane b) optimally-inclined plane*

The computed values of global real-sky irradiation were averaged for all 79 Slovak districts (Fig. 6). The figure shows the highest potential in southern districts situated in the Danubian lowland with annual daily average of irradiation above 3.2 kWh/m^2/day. The values of available solar irradiation decrease in the northern direction with the lowest values just above 2.8 kWh/m^2/day in most northern districts. The similar spatial pattern can be observed for average daily sums of irradiation on optimally-inclined planes, however, the minimum values are still above 3.2 kWh/m^2/day and maximum around 3.8 kWh/m^2/day.

Conclusions

An improved knowledge of spatial distribution and dynamics of solar energy resources is needed for the inclusion of these environmentally-friendly technologies into energy systems. The increasing share of solar energy in the energy system of many countries, including Slovakia, will require a better understanding of solar radiation and its spatial and temporal distribution. The development of new models, techniques and databases is very important for solar energy utilization and forecasting. Our work provided a methodology and database that can be effectivelly used in solar system planning by energy industry, utilities, policy-makers and other users of solar technology.

Our study showed that, in Slovakia, the average daily sums of real-sky solar irradiation on a horizontal plane are about 3.0 kWh/m^2/day with slightly higher values (3.3 kWh/m^2/day) in southern parts of the Slovak territory. Northern, mountainous areas have mixed potential that strongly depends on local topography (areas affected by shadows). The energy yield by solar panels can be increased by optimization of their inclination. The solar panel inclined to 34-46 degrees receive about 2.9-3.8 kWh/m^2/day of solar irradiation in 95% of the territory. The study showed a strong seasonal variation of available solar energy with the highest values during summer months. Horizontal planes in December, in average, receive only 15% of solar irradiation available in June. The optimization of solar panel inclination increases the availability of solar energy during winter up to 30% of June values and thus substantially helps to increase the amount of received irradiation in seasons when the amount of solar energy is naturally low.

In the regional context the most benefiting districts are Komárno and Nové Zámky situated in Danubian lowland with favorable climatic conditions for the utilization of solar energy. It can be noted that several districts with favorable conditions for the utilization of solar energy are amongst the poorest in Slovakia and even in the European Union. Northern, mountainous regions have mixed conditions that require a detailed analysis highly dependent on local topography and geographical conditions.

The presented solar resource database is based on the *r.sun* model and its methodology linked with the open-source environment of GRASS GIS, ground-based measurements of solar irradiation and tri-variate spatial interpolation methods. The future improvement of solar resource databases can rely more on satellite data that reduce the sparsity of current meteorological network in Slovakia.

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Priestorovo distribuovaný odhad solárnych zdrojov pre energetické aplikácie na Slovensku

Súhrn

Slnečná energia je jeden z obnoviteľných zdrojov energie, ktorého význam neustále narastá. Súvisí to s environmentálnymi nákladmi, obmedzenými zásobami fosílnych palív a poklesom nákladov na využívanie solárnej technológie pri výrobe tepla, na chladenie alebo výrobu elektrickej energie. Dostupnosť slnečnej energie na zemskom povrchu závisí od viacerých faktorov. Okrem zemepisnej šírky a astronomických faktorov spôsobujúcich sezónnosť v množstve slnečnej energie sú predovšetkým klimatické faktory (napr. oblačnosť, zákal atmosféry) a georeliéf. Cieľom predloženého príspevku je vytvorenie priestorovo distribuovanej solárnej databázy o zdrojoch slnečnej energie pre územie Slovenska zachytávajúcej priebeh dostupnosti slnečnej energie v priebehu kalendárneho roka. Pri jej vytvorení sa využili klimatické pozorovania z pozemných staníc, ale tiež informácie z existujúcich databáz. V podmienkach členitého reliéfu Slovenska má pre presnosť databázy veľký význam digitálny model reliéfu (najmä pre analýzu zatienenia).

Pri tvorbe databázy sme použili digitálny model reliéfu s rozlíšením rastra 100 m a interpolačné metódy na báze regularizovaného splajnu s tenziou. Pomocou modelu r.sun implementovaného v geografickom informačnom systéme GRASS sme vypočítali množstvo dostupného slnečného žiarenia pre celé územie Slovenska, a to pre horizontálnu rovinu (horizontálne umiestnené panely) a roviny s náklonom optimalizovaným pre maximálny zisk slnečnej energie (Obr. 4, Obr. 5). Tieto analýzy boli vykonané pre jednotlivé mesiace v kalendárnom roku. Výsledky ukazujú, že najvyšší potenciál pre využitie slnečnej energie je na južnom Slovensku, kde dosahuje

priemerné ročné hodnoty až 3,3 kWh/m^2/deň. V členitom reliéfe severného a stredného Slovenska je využiteľnosť významne ovplyvnená formami okolitého reliéfu (napr. údolné polohy majú menej dostupného žiarenia pre zatienenie okolitým reliéfom). Priemerná ročná hodnota dostupného žiarenia na horizontálnu plochu za jeden deň je okolo 3,0 kWh/m^2/deň. Medzi okresy s najvyšším priemerným potenciálom patria okresy Nové Zámky a Komárno s priemernými hodnotami za okres 3,3 kWh/m^2/deň (Obr. 6). Najnižšie hodnoty dosahujú severné okresy s priemernými hodnotami okolo 2,8 kWh/m^2/deň.

Obr. 1 Pozemné meteorologické stanice s meraním slnečnej radiácie a digitálny model terénu odovodený z dát SRTM

Obr. 2 Priemerný denný úhrn globálneho žiarenia pri jasnej oblohe na horizontálnu rovinu a) ročný, b) za mesiac jún, c) za mesiac december

Obr. 3 Priemerný denný úhrn globálneho žiarenia na horizontálnu rovinu a) ročný, b) za mesiac jún, c) za mesiac december

Obr. 4 Uhol optimálneho naklonenia južne orientovaného panelu s maximálnym celoročným energetickým ziskom slnečného žiarenia

Obr. 5 Priemerný denný úhrn globálneho žiarenia na optimálne naklonenú južne orientovanú rovinu a) ročný, b) za mesiac jún, c) za mesiac december

Obr. 6 Regionálna variabilita slnečnej energie v rámci okresov Slovenska pre a) horizontálnu rovinu b) optimálne naklonenú rovinu