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Mechanical Solar Tracking Systems for Photovoltaic Parks

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Abstract. Increasing the amount of electricity produced by photovoltaic parks can be achieved by using mechanical solar tracking systems. One of the challenges is represented by the land area available for installing a photovoltaic park. To use the full potential of a land of a certain shape and surface, the paper proposes an optimization algorithm for the installation of fixed or mobile photovoltaic systems with the objective of maximizing the amount of electricity produced. Both fixed systems and mechanical solar tracking systems for photovoltaic module arrays developed in the Renewable Energy Systems and Recycling Research Centre of Transilvania University of Brasov and in other international research centres are presented. Aspects related to their installation, the solar tracking mechanisms used, their technical capabilities and the produced electricity are comparatively analysed.

Keywords: Mechanical Solar Tracking System, Photovoltaic Park, Optimization Algorithm

1. Introduction

According to IRENA (2025), the capacity of renewable energy systems increased in 2024 by 585 GW globally (Fig. 1.1a), of which 452 GW (78%) are provided by photovoltaic systems newly installed mainly in China (277 GW) followed by the European Union and the United States (Fig. 1.1b).

In Romania, the installed capacity of renewable energy systems increased by only 50.8 MW in the same period, reaching 5005.9 MW in 2024 compared to 4955.1 MW in 2023, the share of photovoltaic systems being approximately 50% (25.2 MW) followed by wind systems with 14 MW and biomass systems from agricultural and forestry waste with 9.7 MW (Transelectrica, 2025). In 2024, the total installed capacity of the 550 photovoltaic systems in Romania was 1443 MW with values ranging between 1 kW and 56 MW. Most of them (302 systems) have installed capacities of less than 1 MW followed by 187 photovoltaic systems with installed

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capacities between 1 and 5 MW, 44 systems with capacities between 5 and 10 MW, 8 systems with capacities between 10 and 20 MW and only 9 systems with capacities between 20 and 60 MW (Fig. 1.2).

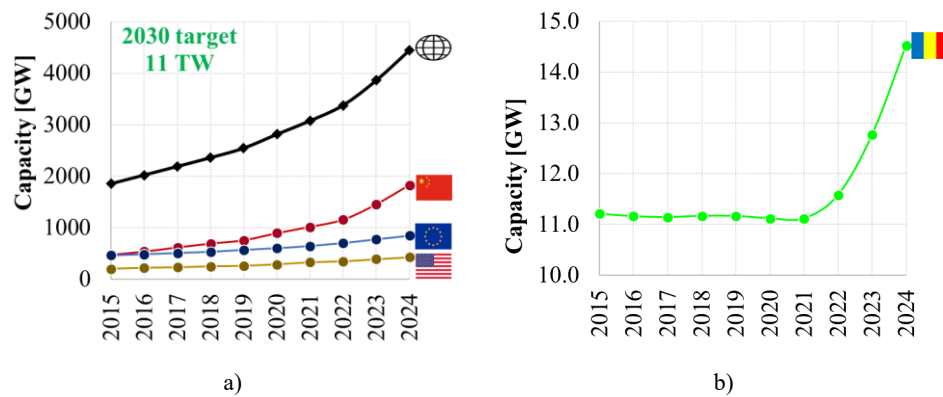


Fig. 1.1 Evolution of worldwide installed power of (a) renewable energy systems and (b) photovoltaic systems [IRENA, 2025].

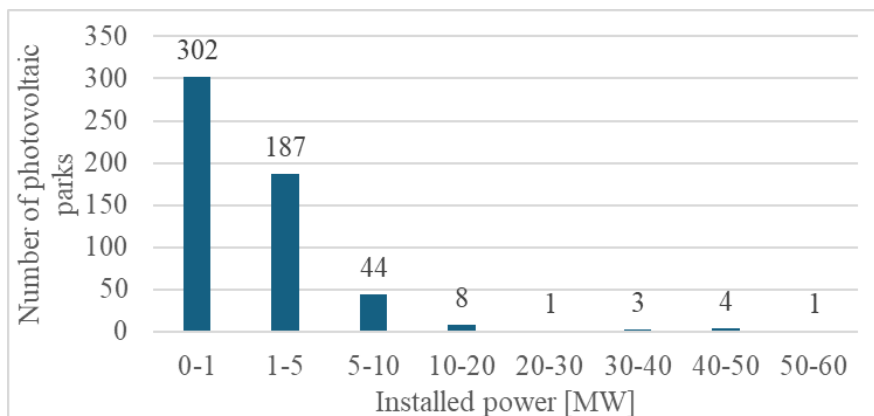


Fig. 1.2 Photovoltaic systems number distribution in Romania in 2024 [Transelectrica, 2025].

Tab. 1.1 The largest Romanian photovoltaic parks, fixed and with mechanical solar tracking systems

Town	County	Type	Year	Power	Land surface		Production	
				MW	ha	ha/MW	MWh	MWh/ha
Livada	SM	fix	2013	56,00	135	2,41	50837	376,57
Ucea de Sus	BV	fix	2013	46,00	122	2,65	56533	463,39
Izvoarele	GR	fix	2013	42,50	125	2,94	66894	535,15
Slobozia	GR	fix	2013	38,40	113	2,94	58527	517,94
Miercurea SB	SB	fix	2013	23,00	58	2,52	25415	438,19
Calafat	DJ	monoaxial	2023	6,00	10	1,70	9600	941,18
Șiria	TM	monoaxial	2022	5,70	9	1,63	8700	935,48
Teiuș	AB	monoaxial	2023	4,80	10	2,08	7100	710,00
Aiud	AB	monoaxial	2023	4,70	6,6	1,40	6800	1030,30
Feldioara	BV	biaxial	2016	4,00	8	2,00	6940	867,50

Table 1.1 presents largest Romanian photovoltaic parks with fixed installation and with mono- and biaxial mechanical solar tracking systems installed until 2023, with available electricity production data in 2024. The investigated fixed photovoltaic parks have a land occupation rate between 2.41 and 2.94 ha/MW, while those equipped with mechanical solar tracking systems require less land, between 1.4 and 2.08 ha/MW. Also, in terms of electricity reported to the occupied land area, photovoltaic systems with mechanical solar tracking systems have advantages over fixed systems: systems with mechanical solar tracking had specific annual productions between 710 and 1030 MWh/ha, while in the case of fixed ones, values between 376 and 535 MWh/ha were obtained.

The mono- and biaxial mechanical solar tracking systems used in photovoltaic parks are classified into four main categories: equatorial, pseudo-equatorial, azimuthal and pseudo-azimuthal (Fig.1.3). Several mechanisms are used, ranging from plane and spatial articulated bar mechanisms to cam mechanisms. In terms of actuation, linear and rotary actuators are used, usually electric but hydraulic ones can be found, one for each rotational movement, but there are also mechanisms in which both rotations are performed using a single actuator or parallel mechanisms in which three or four actuators are used to perform the two rotational movements.

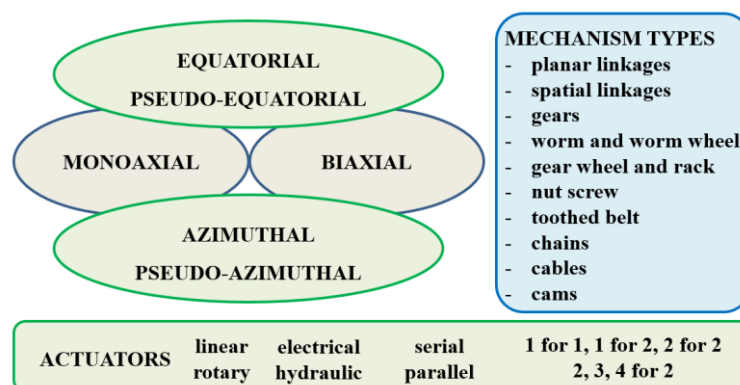


Fig. 1.3 Characteristics of mechanical solar tracking systems for photovoltaic parks.

Fig. 1.4a shows a fixed photovoltaic park in which the rows of photovoltaic modules are aligned with East-West direction and tilted to the horizontal plane at the optimal angle (χ) that ensures maximum energy production on an annual basis. This type of photovoltaic park has the simplest supporting structure, which is made up of metallic poles anchored in the ground and metallic platforms to support the photovoltaic modules.

Fig. 1.4b shows a photovoltaic park equipped with a monoaxial pseudo-azimuthal mechanical solar tracking system diurnally rotating with the angle ϵ_n the rows of photovoltaic modules around North-South horizontal axes of rotation. The metallic platforms supporting the rows of photovoltaic modules are interconnected through parallelogram type linkage mechanism driven by a rotary actuator through a nut-screw mechanism.

Fig. 1.4c shows a photovoltaic park equipped with azimuthal biaxial mechanical solar tracking systems consisting of circular platforms, each platform supporting several rows of photovoltaic modules. Each platform rotating with the azimuthal angle ψ_n on a circular track around a vertical axis of rotation being driven by a rotary motor through a gear reducer. The rows of photovoltaic modules are interconnected through a planar linkage mechanism driven by a linear actuator, simultaneously rotating with elevation angle α_n the rows around horizontal axes.

Thus, the mono- and biaxial mechanical solar tracking system structures are increasingly more complex, and the associated increased costs should be covered by the increased amount of the energy yield, compared with fixed one.

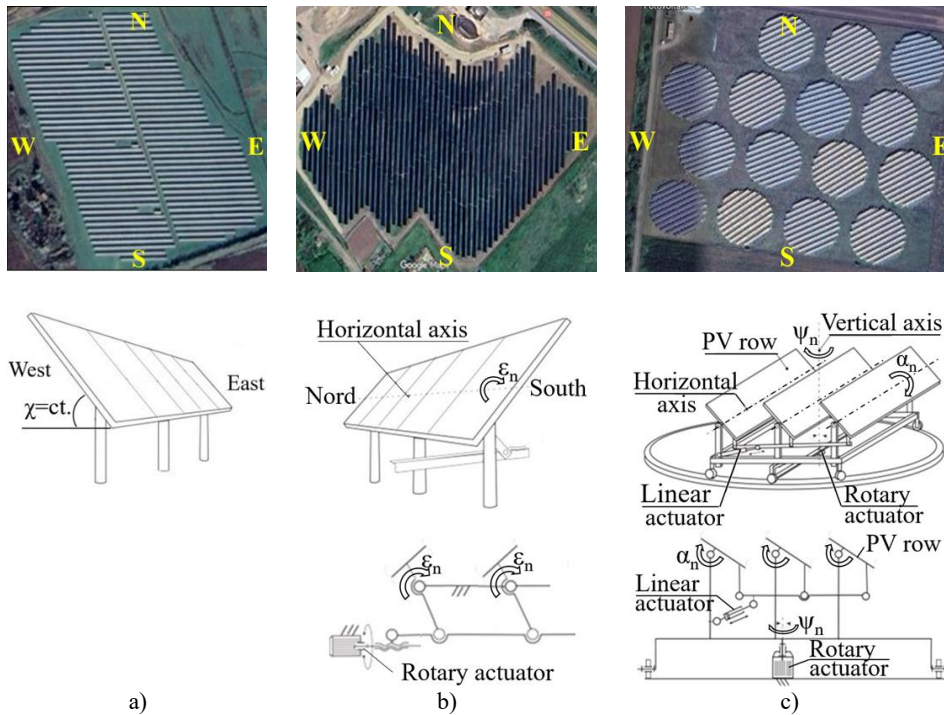


Fig. 1.4 Romanian photovoltaic parks with (a) fixed installation, (b) with monoaxial [Shingleton, 2000] and (c) biaxial [Chen, 2009] mechanical solar tracking systems.

In Fig. 1.5a a biaxial pseudo-equatorial mechanical solar tracking system with two linear actuators is shown, one for the diurnal movement (1) and the second for the elevation movement (2). The biaxial azimuthal mechanical solar tracking system in Fig. 1.5b is driven by a single rotary actuator that ensures both diurnal (1) and elevation (2) movements. The biaxial azimuthal mechanical orientation system in Fig. 1.5c is driven by a rotary actuator for the diurnal movement (1) and a linear actuator for the elevation movement (2) [Vişa et al., 2015].

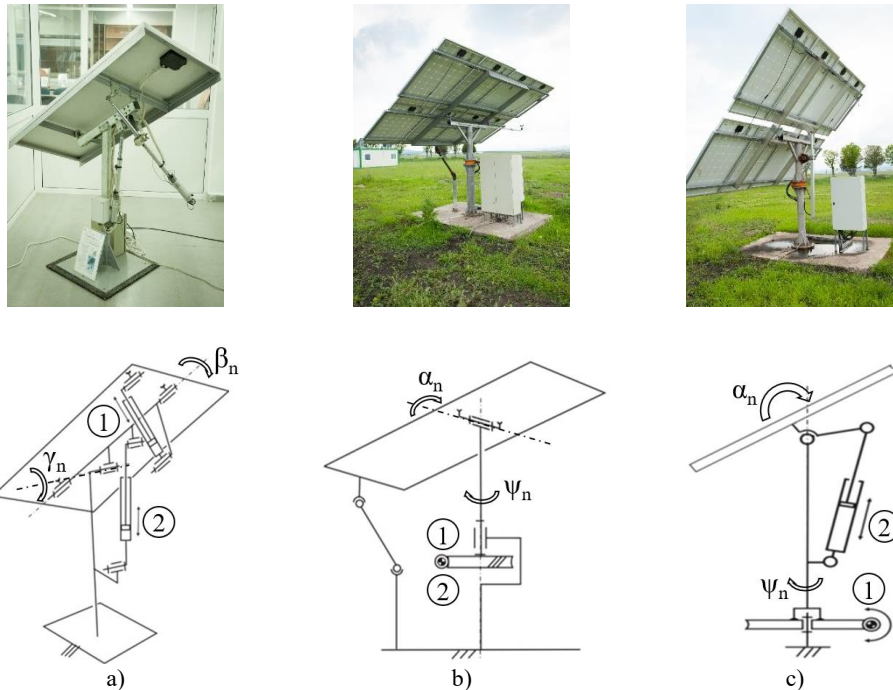


Fig.1.5 Biaxial mechanical solar tracking systems: pseudo equatorial for photovoltaic modules with two actuators (a) and azimuthal with one actuator (b) and with two actuators (c) [Visa et al., 2015].

Fig.1.6 shows a monoaxial pseudo azimuthal mechanical solar tracking system equipped with two linear actuators that provide a diurnal angular stroke of 180° to the photovoltaic modules rows interconnected through parallelogram mechanisms.

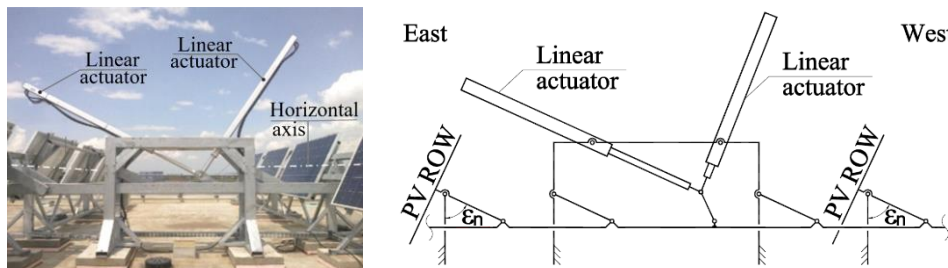


Fig. 1.6 Monoaxial pseudo azimuthal mechanical solar system for rows of photovoltaic modules [Moldovan et al., 2015]

2. Methodology

2.1 Fixed photovoltaic systems

The possibilities of arranging the rows of photovoltaic modules in relation to the sides of the available land are presented in Fig. 2.1. The rows of photovoltaic modules can be placed with one of the sides in the N-S direction, the other side

forming with the vertical the diurnal angle ε_n (Fig. 2.1a), respectively with one of the sides in the E-V direction, the other side forming with the horizontal plane the elevation angle ρ_n (Fig. 2.1b). In the case of fixed photovoltaic systems, the amount of received solar energy is maximum in the second case (Fig. 2.1b) because the available solar energy reaches its maximum value at noon. For this reason, only the variants of placing the photovoltaic rows with one side in the E-V direction will be further analysed.

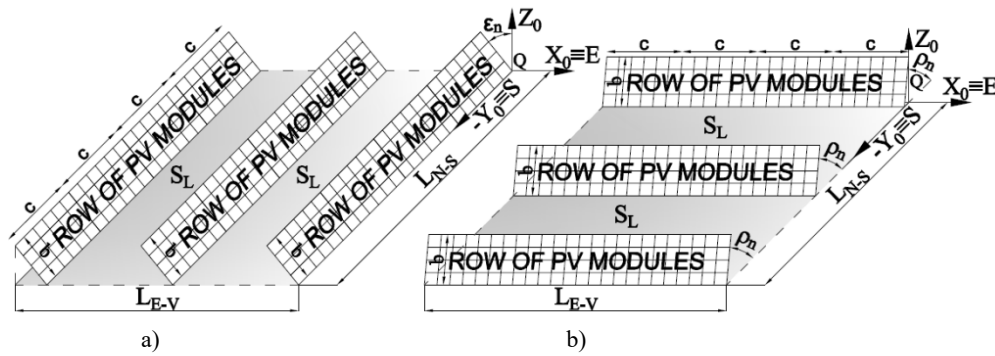


Fig. 2.1 Possibilities for placing rows of photovoltaic modules in relation to the sides of the land.

The mathematical model proposed for the calculation of the solar energy received by the rows of photovoltaic modules is based on the following input parameters:

- surface of the available land, S_L [m²]
- surface of the photovoltaic modules, S_{PV} [m²]
- land length in the N-S and E-V directions, respectively, L_{N-S} [m], L_{E-V} [m]
- width and length of the photovoltaic modules, b and c [m] respectively.

The land shape index is further defined:

$$q = L_{E-V} / L_{N-S} \quad (1)$$

The limits between which this index varies are presented in Fig. 2.2, resulting in a minimum value of the land shape index (q_{min}) for the case presented in Fig. 2.2a and respectively a maximum (q_{max}) for the case presented in Fig. 2.2b. The shape index q_{min} corresponds to the most unfavourable configuration of the available land, namely the case in which its size in the East-West direction is equal to the length (c) of a photovoltaic module. In Fig. 2.2a, the additional land areas (S_d), required in the case of the minimum value of the land shape index due to the distance (d) that must be left between the rows to avoid their mutual shading, are highlighted. The shape index q_{max} corresponds to the most favourable configuration of the available land, namely the case in which its size in the East-West direction is large enough for the installation of a single photovoltaic row (made up of several photovoltaic modules) to cover an imposed electrical energy demand.

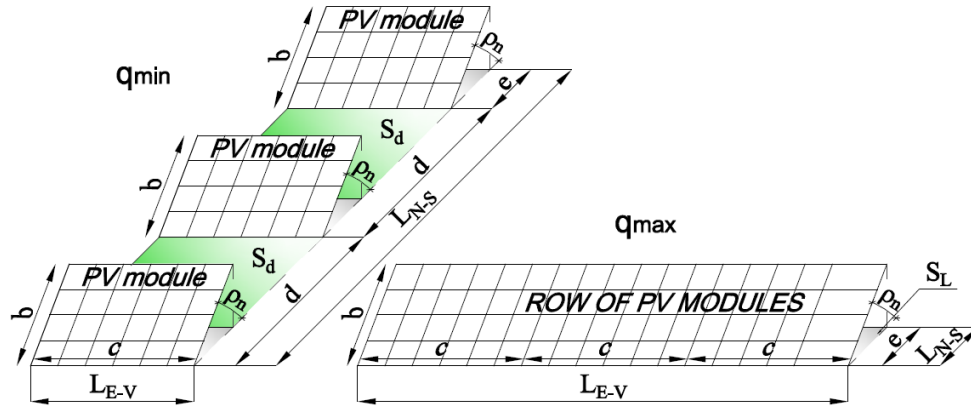


Fig. 2.2 Extreme placement possibilities of photovoltaic modules.

The length of the land occupied in the North-South direction by a number (n_r) of photovoltaic rows, located at a distance (d), is obtained based on the scheme given in Fig. 2.3 with the equation:

$$L_{N-S} = (n_r - 1) \cdot d + b \cdot \cos \rho_n \quad (2)$$

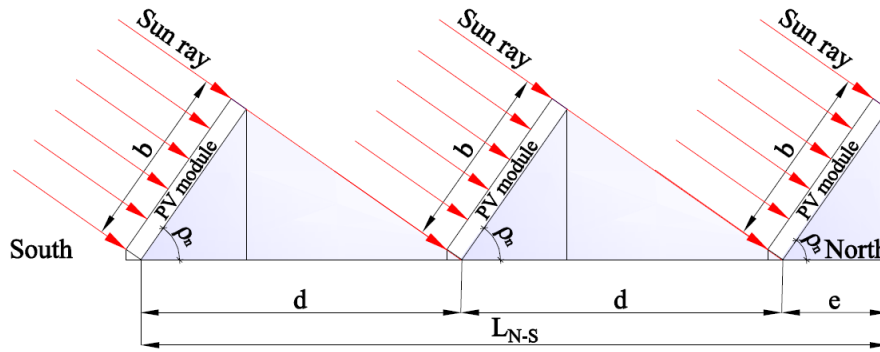


Fig. 2.3 Calculation scheme for the length of the occupied land in the N-S direction.

In the case of a single photovoltaic row ($n_r = 1$) the length of the land occupied in the N-S direction becomes:

$$L_{N-S} = b \cdot \cos \rho_n \quad (3)$$

The land occupation index, O_L [-], is determined by reporting the surface of the occupied land, S_L [m^2], to the surface of the photovoltaic modules, S_{pv} [m^2] with:

$$O_L = S_L / S_{pv} = (L_{N-S} \cdot L_{E-V}) / (b \cdot c \cdot n_{pv}) = ((n_r - 1) \cdot d + b \cdot \cos \rho_n) / (b \cdot n_r) \quad (4)$$

To calculate the optimal distance (d) for placing the photovoltaic rows and their optimal tilt angle (ρ_n) depending on the required number of rows (n_r), the notion of the direct solar energy daily received by an equivalent row, $E_{n.d.er}$ [$Wh/(m^2 \cdot day)$] is introduced, and calculated with the equation:

$$E_{n,d,er} \approx [E_{n,d,fr} + (n_r - 1) \cdot E_{n,d,r}] / n_r \quad (5)$$

where $E_{n,d,fr}$ is the direct solar energy daily received by the first row which can be calculated according to the intensity of the received direct solar irradiance ($B_{n,j}$) at each moment j of a day ($j = 1 \dots m$) considered constant in the time interval Δt using the equation:

$$E_{n,d,fr} \approx (\sum B_{n,j} - (B_{n,1} + B_{n,m})/2) \cdot \Delta t \quad (6)$$

$E_{n,d,r}$ is the direct solar energy received daily by the following $(m-1)$ rows affected by mutual shading, described by the equation:

$$E_{n,d,r} \approx (\sum B_{n,r,j} - (B_{n,r,1} + B_{n,r,m})/2) \cdot \Delta t, \text{ for } s \leq d \quad (7)$$

In this equation, only the values of the intensity of the received direct solar irradiance $B_{n,r,j}$ corresponding to the moments j in which the shadow length (s) of the rows of photovoltaic modules is less than or equal to the distance (d) between the rows are taken into account, considering that even partial shading of the photovoltaic modules causes the decrease of the electricity production [Drif et al, 2012; Garcia et al, 2008; Lorenzo et al, 2011; Martinez-Moreno et al, 2010].

The direct solar irradiance received by each row of photovoltaic modules is calculated with the equation:

$$B_n = B \cdot \cos v \quad (8)$$

where the incidence angle (v) is calculated with the equation:

$$v = \arccos[\cos p \cdot \cos(\varepsilon - \varepsilon_n)] \quad (9)$$

The shadow length (s) of the photovoltaic module rows, necessary to verify the condition in relation (8), is determined based on the calculation scheme in figure 2.4 depending on the elevation (α) and azimuth (ψ) solar angles with the equation:

$$s = b \cdot (\cos \rho_n + \sin \rho_n \cdot \cos \psi / \tan \alpha) \quad (10)$$

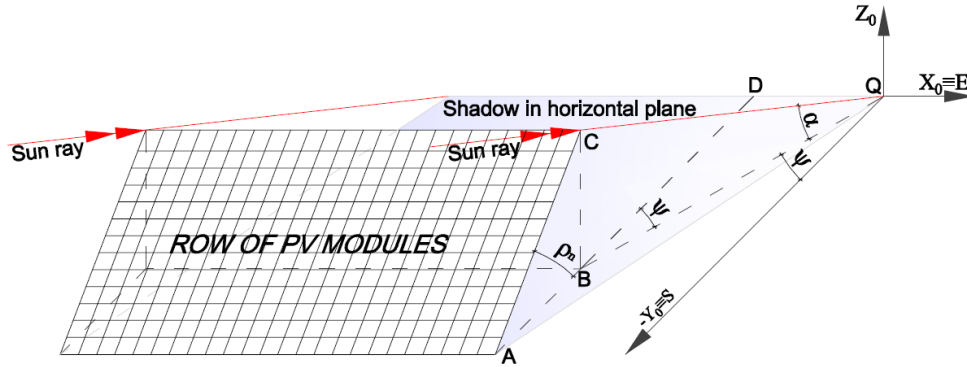


Fig. 2.4 Calculation scheme for the shadow length of a row of photovoltaic modules.

The direct solar energy yearly received by the first row, $E_{n,y,fr}$ [Wh/(m²·year)] and respectively by an equivalent row, $E_{n,y,er}$ [Wh/(m²·year)], from a photovoltaic system composed of a number (n_r) of fixed rows, is obtained by summing the daily captured solar energy calculated with equations (7) and (8), assigning to the cloud crossing factor (CCF) the values corresponding to each period of the year.

$$E_{n,y,fr} \approx \sum E_{n,d,fr} \quad E_{n,y,er} \approx \sum E_{n,d,er} \quad (11)$$

The specific solar energy yearly received by the first row $e_{n,y,fr}$ [Wh/(m²·year)] and respectively by an equivalent row, $e_{n,y,er}$ [Wh/(m²·year)] are calculated with:

$$e_{n,y,fr} = E_{n,y,fr} / O_L; \quad e_{n,y,er} = E_{n,y,er} / O_L \quad (12)$$

2.2 Photovoltaic systems with mechanical solar tracking systems

In the case of mono-axial mechanical solar tracking systems, the extreme possibilities of placing the rows of photovoltaic modules on the available land are presented in Fig.2.5.

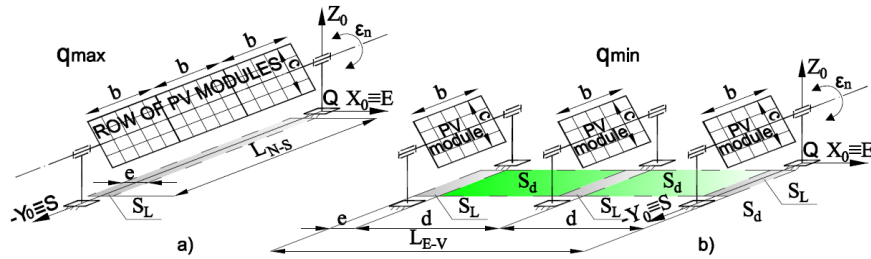


Fig. 2.5 Extreme placement possibilities of photovoltaic rows.

In the case of biaxial mechanical solar tracking systems, the main types of mechanisms are pseudo-equatorial (Fig.2.6a) and pseudo-azimuthal (Fig.2.6b).

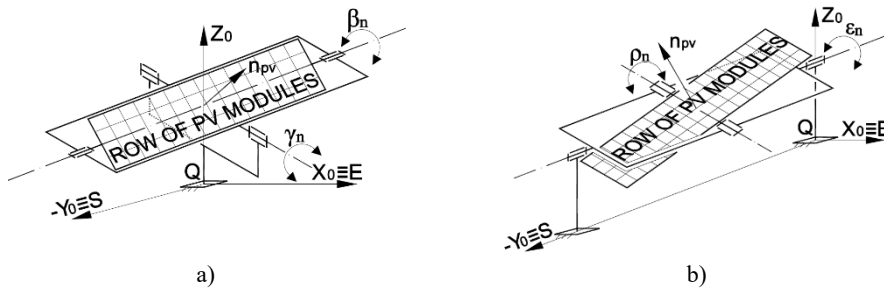


Fig.2.6 Biaxial mechanical solar tracking systems with pseudo-equatorial (a) and pseudo-azimuthal (b) mechanisms.

The incidence angle of the pseudo-equatorial mechanism is calculated with the relation (17) and for the pseudo-azimuthal one with the equation (18):

$$v = \arccos [\cos \beta \cos \beta_n \cos(\gamma - \gamma_n) + \sin \beta \sin \beta_n] \quad (13)$$

$$v = \arccos [\cos \rho \cos \rho_n \cos(\varepsilon - \varepsilon_n) + \sin \rho \sin \rho_n] \quad (14)$$

The payback period of the investment in the photovoltaic system is calculated with:

$$P = I / R \quad (15)$$

where

I is the specific investment, [€/m²], necessary for the implementation of the photovoltaic system which is calculated according to the specific costs of purchasing

and developing the land P_L [€/m²] and respectively the purchase and installation of the photovoltaic system P_{pv} [€/m²], with equation:

$$I = (P_{pv} + O_L \cdot P_L) \quad (16)$$

Specific annual revenues, R [€/m²·an)], generated from the operation of the photovoltaic system, are calculated based on the price of the electricity introduced into the network, P_e [€/MWh] and of the price of Green Certificates received for each MWh introduced into the grid, P_{GC} , [€/GC], with equation:

$$R = E_{n.y.er} \cdot (P_e + P_{GC}) \quad (17)$$

3. Case study

The proposed methodology is further used to implement three photovoltaic parks (fixed photovoltaic park, photovoltaic park with a mono-axial mechanical solar tracking system and photovoltaic park with a bi-axial mechanical solar tracking system) on the available areas within the GENIUS campus (Green, Energy Independent University Campus) of Transilvania University of Brasov (Fig. 3.1). The core of this campus, the Institute for Research, Development and Innovation of Transilvania University of Brasov (ICDT), was developed during 2009-2012 through the project RDI Institute: High Tech Products for Sustainable Development (PRO-DD) financed from European structural funds (POS-CCE, Axis 2, O.2.2.1, ID 123, SMIS 2637) and from the University's own funds [Visa and Moldovan, 2020]. The project, developed by teams of experts from the University, combines advanced concepts of energy efficiency, energy saving and renewable energy systems. The Institute consists of 12 buildings with low energy consumption (79 kWh/m²/year) partly covered from renewable energy sources by photovoltaic, solar thermal, geothermal and wind turbine systems. In the immediate vicinity of the Institute, areas have been provided for the master's school, students dormitories, administrative buildings, conference centre, sports centre and dendrological park. In the western part of the land, an area of approximately 3.5 hectares is available for the implementation of a photovoltaic (PV) park that will provide the electricity needed for the campus.

Further on, the possibility of implementing three distinct photovoltaic systems (a fixed system, one with a mono-axial mechanical solar tracking system and one with a bi-axial mechanical solar tracking system) is evaluated on three identical land surfaces in terms of dimensions and orientation (Fig.3.2). The three land surfaces (S1, S2 and S3) are identical, each having 4000 m², a length of 100 m in the E-W direction and 40 m in the N-S direction. To avoid shading of the photovoltaic park by the Institute buildings located in the eastern part of the land, a protective distance of 50 m was left between the buildings and the three photovoltaic parks. In the northern part of the land there are two car garages with ground floor height regimes which, however, do not generate shading.

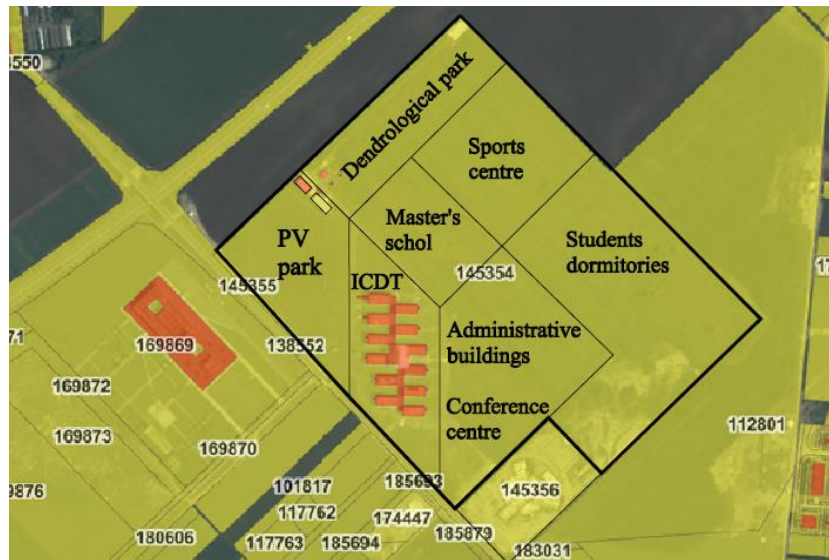


Fig. 3.1 GENIUS Campus of Transilvania University in Brasov.

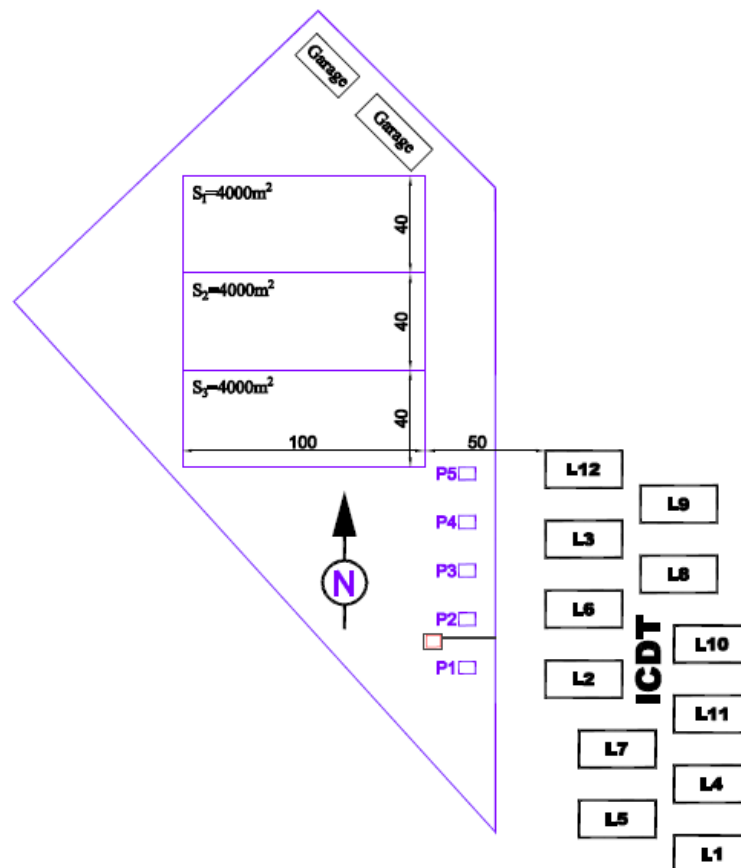


Fig. 3.2 Land available for the installation of the photovoltaic systems.

Considering Brasov as the implementation location, numerical simulations are carried out to determine the optimal values of the elevation of the photovoltaic module rows and the distance between the rows, for which maximum values are obtained for the solar energy yearly received ($E_{n,y,er}$) and for the annual specific solar energy yearly received ($e_{n,y,er}$). In the simulations, an average annual value of the turbidity factor $T_L \approx 3$ is considered [Visa et al, 2020].

3.1 Fixed photovoltaic systems

The mathematical model proposed for evaluating the payback period of the investment can identify the optimal solutions for arranging the photovoltaic strings depending on the imposed input parameters. Through numerical simulations, families of curves are obtained for any combination of input parameters that allow the choice of the number of strings, the distance between them and the elevation at which they must be installed to meet the imposed requirements.

If the land shape index has the maximum value the numerical simulations results are presented in Fig. 3.3 where the maximum yearly efficiency in receiving solar energy $\eta_{y,max} = 67.75\%$ is obtained for the optimal tilt angle $\rho_{n,optim} = 36^\circ$.

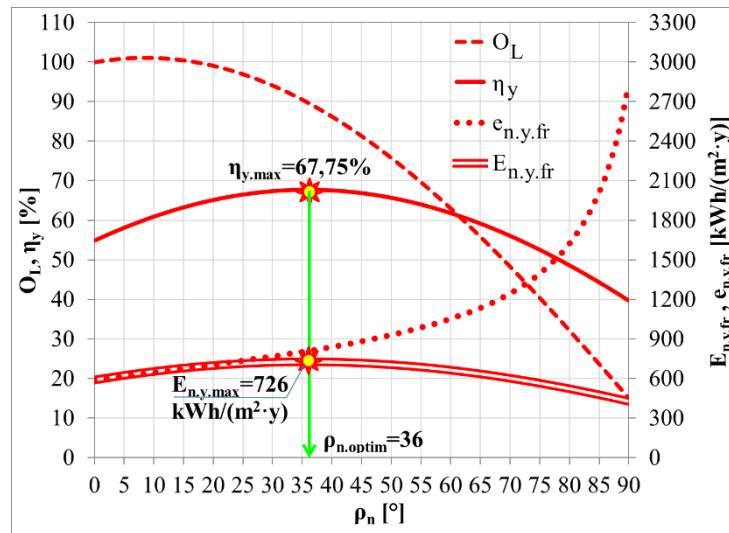


Fig. 3.3 Variation of the yearly efficiency in receiving solar energy (η_y), solar energy yearly received ($E_{n,y,er}$), specific solar energy yearly received ($e_{n,y,er}$), land occupancy index (O_L).

Based on Fig. 3.3, the yearly efficiency in receiving solar energy can be quickly evaluated for situations where the elevation of the photovoltaic rows is required for aesthetic, constructive or wind and/or snow load resistance reasons. At the same time, the land occupancy rate can be evaluated using the land occupancy index (O_L). It is observed that the specific solar energy yearly received ($e_{n,y,er}$) by an equivalent row reaches a maximum value for a 90° tilt angle of the photovoltaic modules

(vertical mounting) due to the reduction in the occupied land area but the solar energy yearly received ($E_{n,y,er}$) is minimum.

If the land shape index has a minimum value, corresponding to the situation in which it is possible to install a single photovoltaic module per row and a maximum number of fixed rows in the North-South direction, numerical simulations are performed to determine the optimal tilt and spacing of the photovoltaic module rows to obtain the maximum value of the direct solar energy yearly received by an equivalent row ($E_{n,y,er}$). The results of the numerical simulations are presented in Fig. 3.4 according to which in the case of $d/b=1$, the maximum yearly efficiency in receiving solar energy is 54.89% when the strings are positioned horizontally, for non-zero elevation values, the yearly efficiency in receiving solar energy has reduced values due to very long periods of mutual shading. For $d/b=1.5$ the yearly efficiency in receiving solar energy reaches a maximum value of 59.71% for a 10° tilt. For $d/b=2$ the yearly efficiency in receiving solar energy reaches the maximum value of 63.86% at a slope of 21° , and for $d/b=3$ the yearly efficiency in receiving solar energy reaches the maximum value of 67.13%, at a slope of 33° .

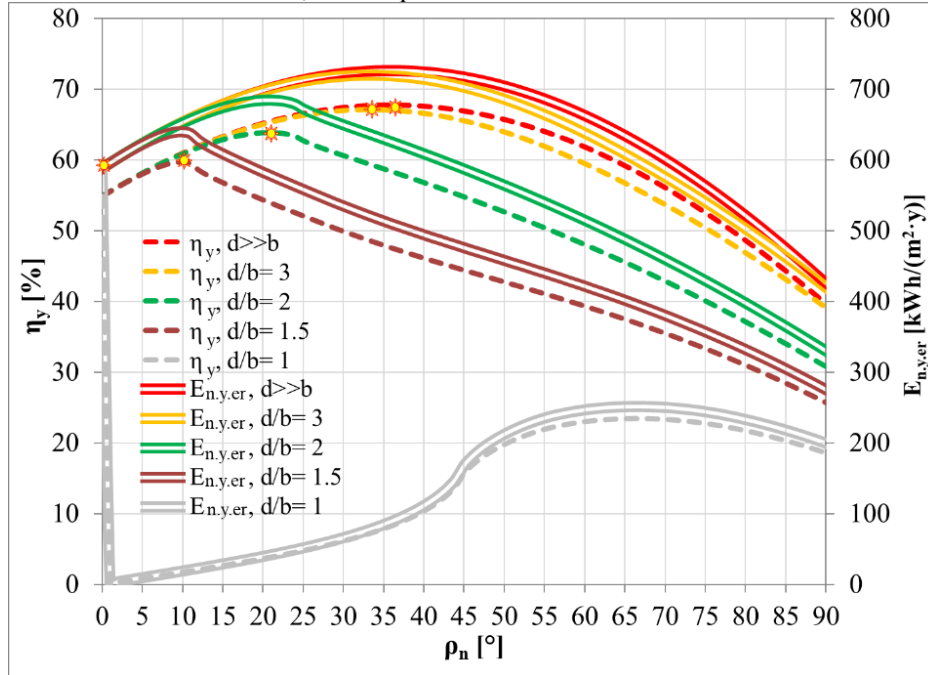


Fig. 3.4 Variation of the yearly efficiency in receiving solar energy (η_y), of the direct solar energy yearly received by the first row ($E_{n,y,fr}$) and by an intermediate row ($E_{n,y,r}$) depending on the distance (d) between the rows.

For the available land having a rectangular shape with a length of 100 m in the East-West direction and a length of 40 m in the North-South direction (Fig.3.2), considering the optimal tilt angle of 33° for the $d/b=3$ ratio, the arrangement presented in Fig.3.5 results, where 7 rows of 88 photovoltaic modules can be installed. The 616 photovoltaic modules, each with a power of 585 W, have a total installed power of 360 kW. Seven inverters with a power of 50 kW will be installed,

one for each row of photovoltaic modules. The electrical energy generated by the photovoltaic system, estimated at 396,396 kWh/year, will generate annual revenues of 55,495 euros which will lead to a recovery of the investment of 117,027 euros in 2.11 years. The estimated benefits over a 15-year period of use of the photovoltaic system amount to 715,405 euros.



Fig.3.5 Possible arrangement fixed rows of the photovoltaic system.

3.2 Photovoltaic systems with mechanical solar tracking systems

In the case of a monoaxial mechanical solar tracking system, keeping the same $d/c=3$ ratio as in the case of the fixed photovoltaic system, the maximum yearly efficiency in receiving solar energy is approximately 73% (Fig.3.6) for a maximum diurnal angular stroke ($\Delta\epsilon_n$) of 90° ($+45^\circ$ at sunrise, 0° at noon and -45° at sunset).

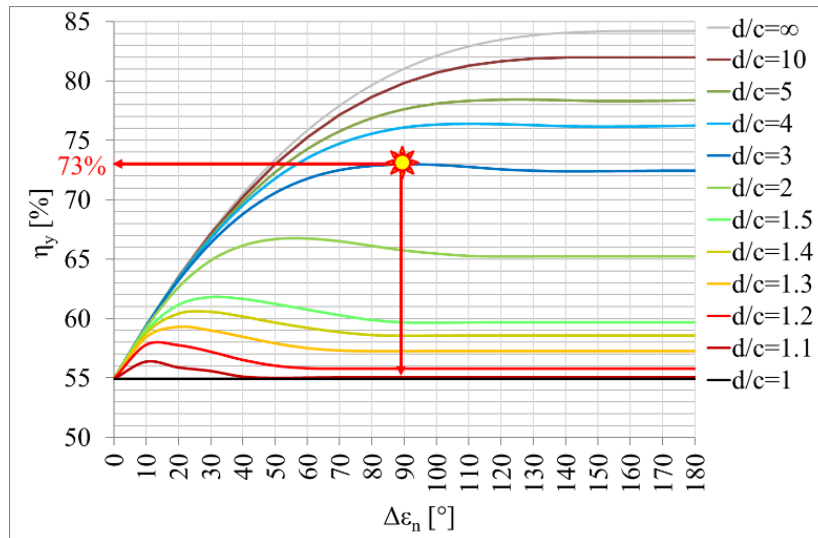


Fig.3.6 Variation of yearly efficiency in receiving solar energy of a monoaxial mechanical solar tracking system.

Under these conditions, for the available land in Fig.3.2, the arrangement presented in Fig.3.7 results, where 17 rows of 34 photovoltaic modules can be installed. The 578 photovoltaic modules, each with a power of 585 W, have a total installed power of 338 kW. For the conversion of the direct current generated by the photovoltaic modules into alternating current, 17 inverters with a power of 20 kW will be used, one inverter for each row of photovoltaic modules. The electrical energy generated by the photovoltaic system, estimated at 405,251 kWh/year, will generate annual revenues of 56,735 euros which will lead to a recovery of the investment of 119,129 euros in 2.10 years. The estimated benefits over a lifetime of the photovoltaic system of 15 years amount to 731,899 euros.

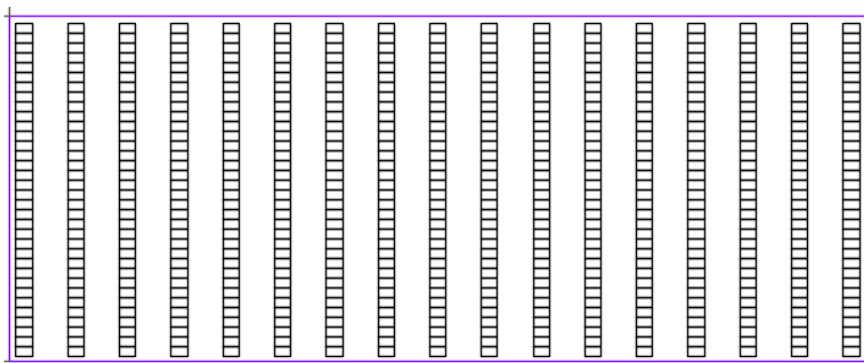


Fig.3.7 Possible arrangement of the rows of the photovoltaic system with monoaxial mechanical solar tracking system.

In the case of a biaxial mechanical solar tracking system, keeping the same $d/b=3$ ratio as in the case of the fixed photovoltaic system, the yearly efficiency in receiving solar energy is approximately 98.5% (Fig.3.8) for a maximum angular stroke of 120° ($+60^\circ$ at sunrise, 0° at noon and -60° at sunset) and a number of 12 elevation adjustment seasons.

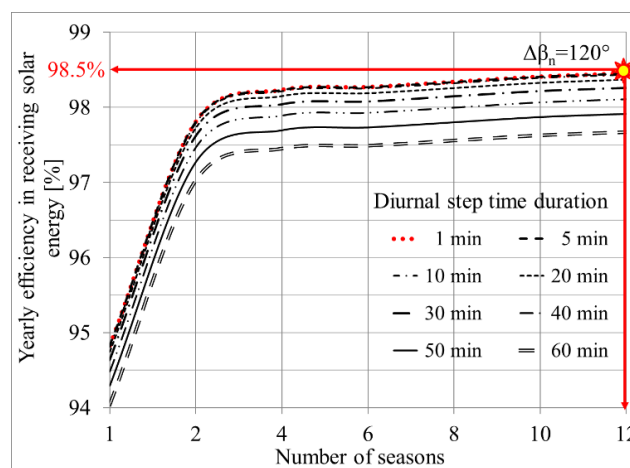


Fig.3.8 Variation of yearly efficiency in receiving solar energy of a biaxial mechanical solar tracking system.

Under these conditions, for the available land in Fig.3.2, the arrangement presented in Fig.3.9 results, where 40 platforms of 15 photovoltaic modules can be installed. The 600 photovoltaic modules, each with a power of 585 W, have a total installed power of 327 kW. For the conversion of the direct current generated by the photovoltaic modules into alternating current, 40 inverters will be used, each with a power of 9 kW, one inverter for each platform of photovoltaic modules. The electrical energy generated by the photovoltaic system, estimated at 567,625 kWh/year, will generate annual revenues of 47,680 euros which will lead to a recovery of the investment of 79,467 euros in 2.02 years. The estimated benefits over a lifetime of the photovoltaic park of 15 years amount to 1,031,284 euros.

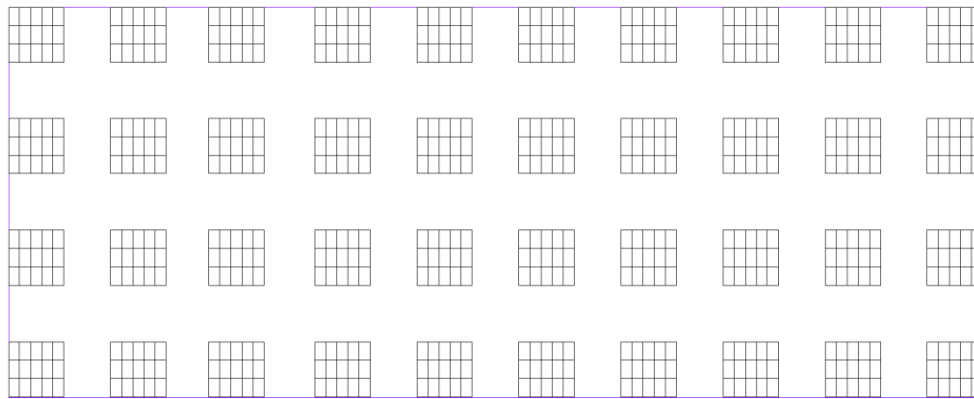


Fig.3.9 Possible arrangement of the platforms of the photovoltaic system with biaxial mechanical solar tracking system.

The results obtained for the three cases are comparatively presented in table 3.1.

Table 3.1 The main characteristics of the three proposed photovoltaic parks

Parameter	Fixed	Monoaxial	Biaxial
Power, kW	360	338	351
Investment, euro	117027	119129	160728
Energy, kWh/year	396396	405251	567625
Payback time, years	2.11	2.10	2.02
Benefits during the lifetime, euro	715405	731899	1031284
Specific energy, kWh/year/m ²	99.10	101.31	141.91
Benefits-investment ratio	6.11	6.14	6.42

4. Conclusions

Aiming at 11 TW from renewable energy sources in 2030, the capacity of renewable energy system continuously increased to 4.5 TW in 2024, especially due to newly installed photovoltaic systems.

Another way to increase the electrical energy output of photovoltaic system rely on mechanical systems for solar tracking with up to 40% compared with fixed photovoltaic systems.

One of the challenges is the available land for installing a photovoltaic park. An optimization algorithm for fixed and mobile photovoltaic systems is presented in the paper to use the full potential of a land of a certain shape and surface while maximizing the electricity output.

A case study is presented for: (1) a fixed PV system, (2) a PV system with monoaxial mechanical solar tracking system and (3) a PV system with biaxial mechanical solar tracking system, installed in the same site of the Renewable Energy Systems and Recycling Research Centre of the Transilvania University of Brasov, Romania.

The highest yearly electrical energy (567,625 kWh) and investment cost (160,728 euro) resulted for the PV system equipped with biaxial mechanical solar tracking system, 43% higher than the energy output (396396 kWh) and 37% higher than de cost (117,027 euro) of the fixed PV system. This is reflected into the lowest payback time (2.02 years) of the biaxial mechanical solar tracking system compared with the fixed one (2.11 years) and in the benefits obtainable during a lifetime of 15 years, 1,031,284 euro for the biaxial mechanical solar tracking system, 44% higher than in the case of fixed one (715,405 euro).

Further research should be undertaken to explore the optimal solutions in arrangements of the rows or platforms of photovoltaic modules in the photovoltaic parks with mono- or biaxial mechanical solar tracking systems.

References

- [1] Chen W., *Solar tracker having louver frames*, 2009, patent no. US 20090032089
- [2] Drif M., Mellit A., Aguilera J., Perez P.J., *A comprehensive method for estimating energy losses due to shading of GC-BIPV systems using monitoring data*, Solar Energy, Elsevier, **86**, 2012, p. 2397-2404.
- [3] Garcia M., Maruri J.M., Marroyo L., Lorenzo E., Perez M., *Partial Shadowing, MPPT Performance and Inverter Configurations: Observations at Tracking PV Plants*, Progress In Photovoltaics: Research And Applications, John Wiley & Sons, **16**, 2008, p. 529-536.
- [4] IRENA, *Renewable power generation costs in 2024*, International Renewable Energy Agency, Abu Dhabi, 2025.
- [5] Lorenzo E., Narvarte L., Munoz J., *Tracking and back-tracking*, Progress In Photovoltaics: Research And Applications, John Wiley & Sons, **19**, 2011, p. 747-753.
- [6] Martinez-Moreno F., Munoz J., Lorenzo E., *Experimental model to estimate shading losses on PV arrays*, Solar Energy Materials & Solar Cells, Elsevier, **94**, 2010, p. 2298–2303.
- [7] Moldovan M. D., Visa I., Neagoe M., *Optimising the strokes and loads of the linear actuators in a two degrees of freedom linkage used in solar tracking systems*, Proceedings of the 14th IFToMM World Congress, Taipei, Taiwan, 2015.
- [8] Shingleton I., *Solar collector and tracker arrangement*, 2000, patent no. US 6058930
- [9] Transelectrica, *List of the RES production units*, 2025.
- [10] Visa I., Duta A., Moldovan M., Neagoe M., Burduhos B., *Solar Energy Conversion Systems in the Built Environment*, Green Energy and Technology, Springer Nature Switzerland AG, 2020.
- [11] Visa I., Jaliu C., Duta A., Neagoe M., Comsit M., Moldovan M., Ciobanu D., Burduhos B., Saulescu R., *The Role of Mechanisms in Sustainable Energy Systems*, Publishing House of the Transilvania University of Brasov, 2015.

- [12] Visa I., Moldovan M., *Energy Efficient Built Environment of the R&D Institute of the Transilvania University of Brasov Romania*, 7th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, 2020