Bulgarian Journal of Agricultural Science, 30 (Suppl. 1) 2024
Agricultural Academy

Impact on the quality and sustainable use of soils from the implementation of large-scale systems for the production and storage of electrical energy from renewable energy sources

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Abstract

Banov, M. & Kolchakov, V. (2024). Impact on the quality and sustainable use of soils from the implementation of large-scale systems for the production and storage of electrical energy from renewable energy sources. *Bulg. J. Agric. Sci., 30 (Supplement 1)*, 83–89

The conducted research is related to establishing the state of the soil cover on the territory of an existing photovoltaic plant for the production of electrical energy. The soils of the areas planned for the construction of a photovoltaic park were also investigated. The obtained results were compared with the characteristics of the soils from the region of the studied sites.

The conducted field and analytical studies on the territory of an existing photovoltaic park testify to the lack of significant impact of electricity production on the state of the soil cover. Conditions are created to preserve soils from intensive cultivation for an extended period of time, with minimal or no application of pesticides, herbicides and fertilizers and no treatments. This is also related to preserving the health of the soil and restoring its fertility.

The need to conduct field studies, prepare studies and prepare annual monitoring reports regarding the short-term, medium-term and long-term impact of the implementation of large-scale systems for the production and storage of electrical energy from renewable energy sources (RES) on ecosystems and biodiversity is proven, as well as on the quality and sustainable use of soils.

The study of the soils in the territories adjacent to the photovoltaic parks provides an opportunity to track the impact that the exploitation of the sites has on the soil cover and to plan actions to overcome the negative impacts.

Examining the state of the soil cover before the construction of a photovoltaic park allows for proper planning of the program for monitoring the objects and drawing up a system of measures to preserve and improve soil fertility on the territory of the objects.

Keywords: photovoltaic plant; photovoltaic park; renewable energy sources; soil health.

Introduction

In recent years, the following crises and conflicts have been observed, which are in many ways related to the development of the agricultural sector:

- Climatic (ecological) crisis.
- Crisis in food and feed production.
- Crisis with energy sources.
- Food and bio-energy conflict.

The natural resource crisis is characterized by decreasing biodiversity, deteriorating soil fertility due to degradation processes, decreasing water resources, decreasing soil resources, etc.

In this context, the issue related to the conflict regarding the production of food and renewable energy from photovoltaic plants (Barron-Gafford al., 2019), as well as achieving a reduction of global warming and climate change, is particularly relevant. This is possible through the construction of alternative energy installations linked to the implementation of international agreements such as the Kyoto Protocol and the Paris Agreement (Miyamoto et al., 2019).

Fossil fuels have been found to be a major source of energy, leading to the release of greenhouse gases (Maamoun et al., 2020). Considering that electricity demand is expected to increase by 56% by 2024 (Rahman et al., 2022). it is imperative to proceed with the construction of alternative sources of energy, which will also reduce the production of carbon emissions (Armstrong et al., 2014).

One of the solutions is related to the development of photovoltaic plants (Wilberforce et al., 2019; Bogdanov et al., 2021). It is no coincidence that at present almost 30% of the world's energy consumption is from solar sources (Azam et al., 2023), with projections for growth (Morcillo et al., 2022). Evidence in this regard is the fact that, as of 2018, total PV capacity was 55% of all new renewable energy capacity (Dunnett et al., 2020).

On the other hand, research shows that the construction of photovoltaic plants has an impact on terrestrial ecosystems (Turney et al., 2011; Armstrong et al., 2016; Chang et al., 2016).

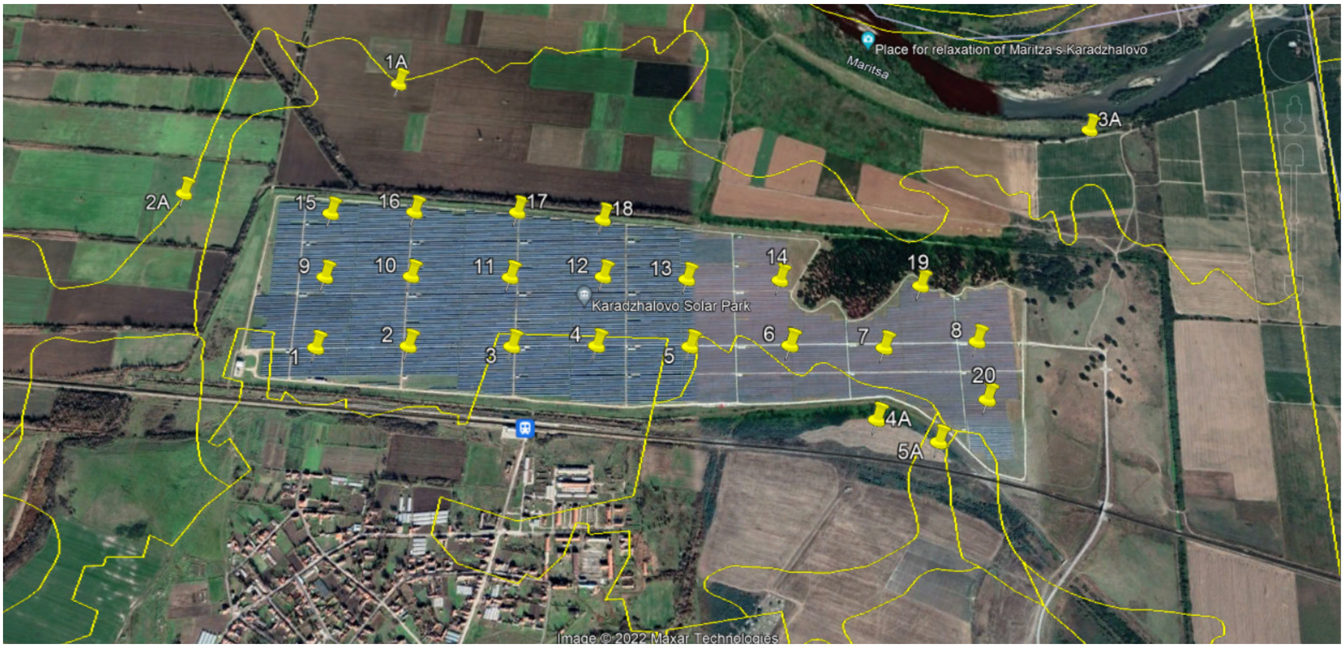
An impact on the climate and soils in the territory of the photovoltaic parks has been established (Hong and Kim, 2008; De Marcoa et al., 2014; Choi et al., 2020).

It has been shown that PV panels can affect air humidity and soil water content (Weinstock and Appelbaum, 2009; Lu, 2013), which is also associated with a reduction in wind speed and turbulence (Armstrong et al., 2016; Zhao, 2016; Yin et al., 2017). Effects on plant communities associated with changes in biomass and biodiversity have been observed (Liu et al., 2019; Zhai et al., 2020; Lambert et al., 2022).

The studies of Zhang et al. testify to the influence of the photovoltaic plants on the environmental components of the construction area, but without significant influence on the soils.

Materials and Methods

A field study of the soils was carried out on the territory of the existing photovoltaic park "Karadzhalovo", located in the land of the village of Karadzhalovo, Parvomai municipally, in the region of Plovdiv, and the adjacent areas in the neighborhood. 20 (twenty) pieces of soil samples were collected at a depth of 0–25 cm in a grid on the territory of the park, and 5 (five) pieces in the neighborhood, covering the soil differences in the area. The location of the samples is presented in scheme 1.



Scheme 1. Location of samples

The study was carried out in two stages – during the period 19.09.2022 – 22.09.2022, and during the period 17.05.2023 – 18.05.2023.

The location of the samples taken during the second stage coincides with those collected during the field survey in September, 2022. This allows a comparison to be made on the basis of the obtained analytical results for the influence of the exploitation of the site on the qualities of the soil cover.

A field observation and soil sampling was carried out on the areas planned for the construction of the "Chirpan" photovoltaic park (located in the lands of the villages of Zetyovo, Zlatna livada and Celina, Chirpan Municipality) and the adjacent areas.

17 soil samples were collected at a depth of 0–25 cm from predetermined plots, as well as from adjacent areas covering the soil differences in the area (Scheme 2).

The collected samples were analyzed for the content of basic nutrients N, P, K, reaction of the environment (pH), content of organic matter (humus), mechanical composition and microbiological activity. The analyses were carried out according to the methods adopted for the country, as follows:

– pH – potentiometric
– mineral N – mod. of Bremner and Kinnaeus
– P_2O_5 – P. Ivanov's method
– K_2O – method of P. Ivanov
– humus – Turin's method
– mechanical composition – pyrophosphate method

Results and Discussion

Existing solar park „Karadzhalovo"

During the field survey, it was established that the majority of the territory of the built in the land of the village of Karadzhalovo, Parvomai Municipality, in the region of Plovdiv Photovoltaic Park and the adjacent areas fall on alluvial-meadow soils, strong, slightly swampy, slightly clayey. A small part falls on highly leached to slightly podzolic cinnamon, uneroded soils.

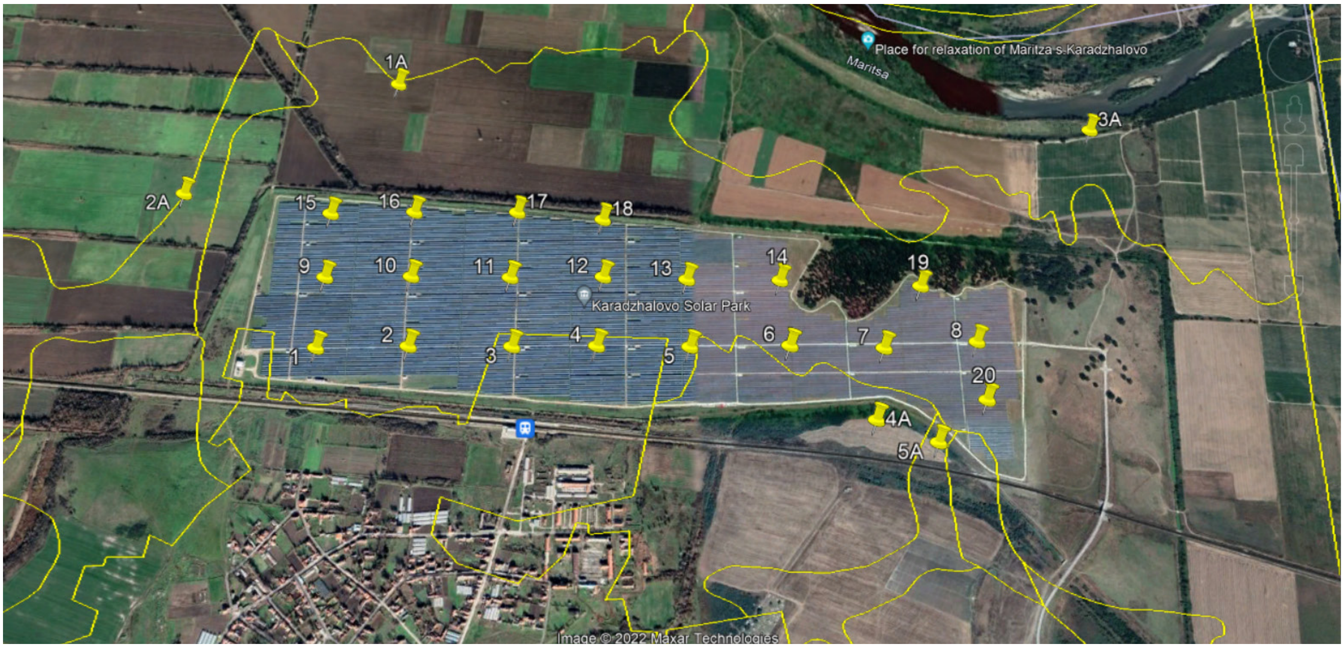
The adjacent terrains in the north, east and west direction fall on alluvial-meadow soils, strong, slightly marshy, slightly clayey. In the southern direction, the adjacent areas are occupied by highly leached to slightly podzolic cinnamon, non-eroded soils, and a small part falls on alluvial /deluvial/ soils, medium strength. In the western direction, the soil difference in the neighborhood is represented by alluvial-meadow soils, powerful.

Description of soils

1. Alluvial-meadow soils, strong, slightly swampy, slightly clayey

They were formed on alluvial deposits. In terms of mechanical composition, the soils are medium sandy-clay. The amount of physical clay in the surface horizon is 37.4%, and that of silt is from 18 to 19%.

Regarding the content of organic matter, they are slightly hu-



Scheme 2. Location of samples

mus – from 1.3 to 1.4% humus in the arable horizon. Their reserves of total nitrogen and total phosphorus are very low. The soil reaction in the surface horizon is neutral /pH in KCl is 5.8/. Carbonates are not found at depth in the profile.

2. Strongly leached to slightly podzolic cinnamon, uneroded soils, medium sandy-clay

They occupy relief alignments, old floodplain river terraces and very weak slopes. They were formed on alluvial deposits. The thickness of the humus-eluvial horizon varies from 28 to 59 cm. The total thickness of the profile is 88–122 cm.

Their mechanical composition is medium sandy-clay. The amount of silt and physical clay in the surface horizon is within 38.2% and from 57.0 to 59.3% in the middle part of the profile.

The content of organic matter in the humus-eluvial horizon varies within the limits of 1.28%. This content defines the soils as poor humus and weakly humus. The determined amounts of total nitrogen and total phosphorus show very low stocking. The soil reaction is very acidic and strongly acidic. Carbonates are established below 98 cm.

3. Alluvial-deluvial soils, medium swampy

They were formed on alluvial deposits. The thickness of their humus horizon is 30–50 cm, and of the profile 60–120 cm.

In terms of mechanical composition, these soils are slightly sandy-clay. The amount of physical clay in the surface horizon is within the limits of 24.4%, and that of silt is 13.6%.

Regarding the content of organic matter, these soils are moderately humus – 3.4% humus. Their stocking of total nitrogen as well as total phosphorus is very low to medium. Their soil reaction in the surface horizon is very strongly acidic to slightly acidic /pH in KCl ranges from 3.7 to 5.2. Carbonates are not found at depth in the profile.

4. Alluvial-meadow soils, medium swampy

They were formed on alluvial deposits. The thickness of their humus horizon is 100–120 cm, and of the profile 140–160 cm.

Their mechanical composition is slightly clayey.

Regarding the content of organic matter, these soils are moderately humus – 2.59% humus. Their reserves of total nitrogen and total phosphorus are low to medium.

The obtained analytical results from the study of the samples collected during the first period of field research on the territory of the existing photovoltaic park "Karadzhalovo" show that the soil reaction is from slightly acidic to neutral (pH in H_2O is from 6.1 to 7.3) and to slightly alkaline at points 10, 11, 12, and 18 (pH in H_2O is from 7.7 to 7.9), which is characteristic of soils with the presence of swamping processes. Alluvial-meadow soils are characterized by a higher content of organic matter, and in the studied soils the indicator varies from 3.15 to 6.96%. With total nitrogen and total phosphorus, these soils are low to medium stocked, and with regard to potassium, they are well-stocked.

The mechanical composition of the studied soils varies from medium sandy-clay (content of physical clay in the surface horizon from 19.9% to 39.9%) to slightly clayey (56.8% to 78.6%). This is mainly due to the heterogeneity of the soil-forming alluvial materials.

Microbiological studies of selected samples from the territory of the park provide information on the microbiological characteristics of soils. The data obtained for the alluvial-meadow soil and the alluvial-deluvial soil from the site "Karadzhalovo" show a significant variation in the number of microorganisms between the 11 sampling points selected for analysis. The greatest differences were found for the number of microscopic fungi (their number was from 2.96 to 21.44. 10^4 CFU/g of absolutely dry soil) and ammonifying bacteria (respectively from 5.22 to 18.19. 10^6 CFU/g absolutely dry soil). This is probably related to the differences in the amounts of incoming fresh organic matter, which is mainly mineralized by the indicated groups of microorganisms. The large number of actinomycetes (up to 16.59. 10^6 CFU/g of absolutely dry soil) and cellulose-decomposing microorganisms (up to 23.01. 10^4/g of absolutely dry soil) shows that there are active processes of degradation of organics that are difficult for microorganisms to digest compounds. In general, the soils are of high biogenicity.

The samples collected during the period 17.05.2023 – 18.05.2023, from the territory of the existing photovoltaic park „Karadzhalovo", were examined in terms of soil reaction, content of organic matter, total nitrogen, total phosphorus and total potassium and distribution of mechanical fractions. No microbiological tests were conducted due to the impossibility of making a comparison with the results of the tests of samples from the period 19.09.2022 – 22.09.2022.

The obtained analytical results testify to the following:

1. The soil reaction of the samples from the territory of the photovoltaic park varies from slightly acidic to neutral (pH in H_2O is from 5.8 to 7.5).

2. The content of organic matter in the samples from the territory of the photovoltaic park changes from 2.40 to 6.14. This defines the soils as medium to highly stocked.

3. The content of total nitrogen and total phosphorus determines the soils from the territory of the photovoltaic park as low to medium stocked, and with regard to potassium, the stocked is good.

4. The mechanical composition of the investigated soils from the territory of the photovoltaic park varies from medium sandy-clay (content of physical clay in the surface horizon from 18.6% to 40.6%) to slightly clayey /49.6% to 85.0% /.

Chirpan Photovoltaic Park

During sampling, it was found that the soil cover in the area of the Chirpan Photovoltaic Park is represented by Medium leached clay loams, slightly and moderately eroded; Medium leached cinnamon forest soils, medium eroded; Moderately leached vertisol, slightly and moderately eroded; Weakly leached vertisol, slightly and moderately eroded; Weakly leached vertisol, moderately eroded; Rendzinas (humus-carbonate), shallow, medium and highly eroded.

Description of soils

1. Weakly leached vertisol, moderately eroded

They were formed on carbonate rock and occupy moderately pronounced slopes.

In terms of mechanical composition, these soils are slightly clayey. The amount of physical clay in the surface horizon is 65.0%.

Regarding the content of organic matter (humus), these soils are moderately humus – from 2.77% to 2.80% humus in A horizon. The supply of total nitrogen and total phosphorus is low. The soil reaction in the humus horizon is alkaline (pH varies from 6.8 to 7.8). Carbonates are detected from the surface.

2. Rendzinas (humus-carbonate), shallow, medium and highly eroded

They occupy steep slopes and were mainly in the southern part of the study area. They were formed on carbonate rocks. The thickness of these soils is 10–30 cm and coincides with that of the humus horizon. Their mechanical composition is medium sandy-clay. The amount of physical clay in the profile is within the limits of 43.8%.

Regarding the content of organic matter, they are medium to humus /4.14% humus content/. The reserve of total nitrogen is low, and of total phosphorus – average. The soil reaction is alkaline (pH in KCl ranges from 7.1 to 7.3). Carbonates are detected from the surface.

3. Moderately leached vertisol, slightly and moderately eroded

These soils were formed on top of carbonate sandy-clay and clay deposits and occupy mostly slopes. The thickness of the humus horizon of these soils is 33–40 cm, and of the profile 80–60 cm. By mechanical composition, they are light-clay, the amount of physical clay in the surface horizon is 71–76%, and that of silt is from 55 to 57 %.

Regarding the content of organic matter, these soils are moderately humus – 2.0–3.4% humus in the surface horizon. Their stocking in the surface horizon with total nitrogen in the surface horizon is weak to medium, and with total phosphorus weak to good. Carbonates settle in the parent rock. The soil reaction in the surface horizon is neutral to slightly alkaline (pH e 5.7).

4. Vertisol, medium and highly eroded

These soils occupy pronounced slopes. They were formed on carbonate sandy-clay and clay deposits.

The thickness of the humus horizon of these soils is 0-30 cm and coincides with the thickness of the profile.

By mechanical composition, they are heavy sandy-clay. The amount of physical clay in the surface horizon is from 48 to 49%, and that of silt varies from 37 to 38%.

The data from the research on the content of organic matter defines these soils as slightly humus – 2.37% humus in the surface horizon. Their reserve in the surface horizon with total nitrogen is weak, and with total phosphorus average. The soil reaction in the surface horizon is slightly alkaline (pH in KCl is 6.95). Carbonates settle from the surface.

5. Weakly leached vertisol, slightly and moderately eroded

They occupy well-pronounced slopes. They were formed on carbonate sandy-clay materials.

In terms of mechanical composition, these soils are slightly clayey. The amount of physical clay in the surface horizon is 62.4%, and in the subsoil is 58.5%. The texture coefficient is 0.9–1.0.

Regarding the content of organic matter, they are low to medium, humus – 2.5%. Stocking with total nitrogen is low, and with total phosphorus – low to medium.

The soil reaction in the humus horizon is slightly acidic (pH 5.25). Carbonates are found 29–30 cm from the surface.

The analytical results of the study of the collected soil samples show that the reaction of the soils in the lands of the villages of Zetyovo and Zlatna livada is slightly alkaline (pH in H_2O varies from 7.2 to 7.3) at points 14, 16 and 17, and alkaline at points 8, 9, 10, 11, 12, 13 and 15 (pH in H_2O is from 7.4 to 7.9). The soil samples in the land of Celina village show that the soil reaction is slightly acidic (pH in H_2O varies from 6.2 to 6.7) at points 1 and 7. The soil reaction is alkaline (pH in H_2O is 7.3 to 7.9) at points 2, 3, 4, 5 and 6. In terms of organic matter content, the studied soils are humus with indicator values from 2.49 to 7.21%/. With total nitrogen and total phosphorus, these soils are low to medium stocked, and with regard to potassium, they are well-stocked.

The microbiological studies of selected samples from the studied areas show the presence of relatively high biogenicity in the Rendzinas and Vertisols, distributed in the area of the sites from the village of Celina, the village of Zetyovo and the village of Zlatna livada. A high number of actinomycetes (20.04.10^6 CFU/g abs. dry soil) and cellulose-decomposing microorganisms (21.47.10^4 CFU/g abs. dry soil) was found for the Rendzinas in the region of the village of Zetyovo, which is an indicator of active decomposition processes of organic compounds that are more difficult to decompose than soil microorganisms. For the two sampling points in the area of the village of Zlatna livada, a relatively low number of ammonifying bacteria was obtained (from 5.88 to 7.11.10^6 CFU/g abs. dry soil) with a higher number of microorganisms than the other taxonomic groups. Rendzinas and Vertisols from the region of the village of Celina are characterized by a higher number of ammonifying bacteria.

Conclusions

1. The conducted field and analytical studies of samples from the territory of the existing photovoltaic park "Karadzhalovo" in the period 19.09.2022 – 22.09.2022, and 17.05.2023 – 18.05.2023, testify to the lack of significant impact of electricity production on the state of the soil cover. The comparison of the obtained analytical results from the two studies, as well as the comparison with the characteristics of the soils from the territories adjacent to the site, shows preservation of the values of the investigated indicators – soil reaction, content of organic matter, total nitrogen, total phosphorus and total potassium and distribution of mechanical factions.

2. It is necessary to carry out such studies regularly over a period of several years in order to confirm the results obtained so far.

3. Conditions are created to preserve soils from intensive cultivation for an extended period of time with minimal or no application of pesticides, herbicides and fertilizers and no treatments. This is also related to preserving the health of the soil and restoring its fertility.

4. The necessity of conducting field studies, the preparation of studies and the preparation of annual monitoring reports regarding the short-term, medium-term and long-term impact of the implementation of large-scale systems for the production and storage of electrical energy from renewable energy sources (RES) on ecosystems is proven and biodiversity, as well as on the quality and sustainable use of soils.

5. Studying the state of the soil cover before the construction of the Chirpan Photovoltaic Park allows for proper planning of the program for monitoring the sites and drawing up a system of measures to preserve and improve soil fertility on the territory of the sites.

6. The study of the soils in the territories adjacent to the photovoltaic parks provides an opportunity to track the impact that the exploitation of the objects has on the soil cover and to plan actions to overcome the negative impacts.

Acknowledgments

The article has been prepared in connection with the results obtained during the execution of a contract between the Association „Association for Production, Storage and Trade of Electricity" and the Agricultural Academy – Sofia.

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Received: **October, 09, 2024**; *Approved*: **October, 14, 2024;** *Published:* **December, 2024**