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REGIONAL DIFFERENCES IN THE SPATIAL DISTRIBUTION AND ENVIRONMENTAL CONSEQUENCES OF PV FARMS IN SOUTHERN ROMANIA

Along with wind energy, photovoltaics (PV) are the main technology options for the shift to a decarbonised energy supply towards a low-carbon economy. Thus, the increasing share of solar energy has been one of the main instruments to be considered under the EU energy efficiency targets, Romania has also assumed. Romania has important solar energy resources to be exploited in the lowlands and low hills in southern and south-eastern parts of the country mainly in relation to the high values of the radiation and sunshine duration parameters. However, apart from the clean and sustainable energy they provide, PV farms also involve some environmental consequences (e.g. land degradation, soil erosion, biodiversity loss). The current paper is seeking to identify and analyse the main regional differences and environmental consequences of PV farms installation and use in Southern Romania based on several indicators: the share/surface of PV farms at County level; the share of PV farms of each land use/cover category; distance to forests, waters, protected areas (SCI, SPA); share of PV farms of main soil types. The resulted statistics enabled the authors to identify the existing and the potential environmental impacts of PV farms on specific natural and man-made environmental components (e.g. land use/cover, soils, water bodies, forests, settlements, roads).

Keywords: *solar energy resources; solar energy; PV farms; Romania.*

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РЕГІОНАЛЬНІ ВІДМІННОСТІ У ПРОСТОРОВОМУ РОЗПОДІЛІ ТА ЕКОЛОГІЧНІ НАСЛІДКИ СОНЯЧНИХ ЕЛЕКТРОСТАНЦІЙ В ПІВДЕННІЙ РУМУНІЇ

Поряд з енергією вітру, сонячна енергій є одним із основних технологічних варіантів для переходу до відновлюваних джерел енергії. Румунія також припускає, що зростаюча частка сонячної енергії є одним із головних інструментів, які слід розглядати в рамках цілей ЄС щодо енергоефективності. Румунія має значні ресурси сонячної енергії, які доцільно використовувати на низовинах і на низьких пагорбах у південній та південно-східній частинах країни, головним чином враховуючи високі значення параметрів тривалості сонячного сяйва. Однак, окрім чистої та стійкої енергії, яку постачають геліоустановки, вони також чинять і деякий несприятливий екологічний вплив (наприклад, стосовно деградації земель, ерозії ґрунтів, втрати біорізноманіття). У цій статті автори зробили спробу визначити та проаналізувати основні регіональні відмінності та екологічні наслідки встановлення та використання геліоустановок у Південній Румунії на основі декількох показників: частка / поверхня геліоустановок на рівні округу; частка їх для кожної категорії землекористування / покриття; відстань до лісів, вод, природоохоронних територій (SCI, SPA), основних типів ґрунтів. Отримані статистичні дані дали змогу авторам визначити існуючі та потенційні впливи геліоустановок на навколишнє середовище, зокрема на конкретні природні та техногенні його компоненти (наприклад, землекористування / покрив, ґрунти, водойми, ліси, селища, дороги).

Ключові слова: *геліоенергетичні ресурси; геліоенергетика; геліоустановки; Румунія.*

Introduction

The increasing demand for clean energy production had significantly influenced the growing share of renewable energy in the electricity sector in Europe (mainly form solar and wind) much faster than the rest of the economy. I.e. between 2005 and 2015, the installed solar PV power has increased from 1.9 GW to 95.4 GW [1]). This had raised questions about the variety, availability and efficiency of energy sources and the related environmental impacts. Thus, as part of the *Clean energy for all Europeans* package, the revised Renewable Energy Directive 2018/2001/EU establishes a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible revision by 2023[1]. This will to continue the EU policy of supporting the transition from fossil fuels to cleaner energy and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions[2] Renewable technologies are considered clean sources of energy and their optimal use will lead to reduced environmental impacts, producing minimum secondary waste, thus being sustainable in relation to the current and future economic and social needs [2]. Nevertheless, all forms of energy generation can have intensive or extensive spatial requirements, thus suggesting "energy sprawl" as another driver of habitat and biodiversity loss, mainly affecting sensitive ecosystems [3,4]. Among all renewables, solar energy is known as the most sustainable energy source, yet involving land and environmental constraints. The "solar electric footprint", defined as the land area required to supply all end-use electricity from solar photovoltaics (PV) [5] is largely using different land resources form agricultural land, followed by shrub land, pasture/hay, grass/herbaceous [6,7]. Albeit Romania has a high potential for renewable energy resources (mainly solar and wind), until recently they were not fully exploited [8-10]. Nevertheless, in the last years, under the EU energy efficiency targets that Romania has assumed, the energy sector faced significant changes, thus increasing the share of solar energy. The most important solar energy resources are found in the lowlands and low hills in southern and south-eastern parts of the country (e.g. Danube Delta, Dobrogea Plateau, and Romanian Plain) mainly in relation to the high values of the radiation and sunshine duration parameters (over 2200 hours/year) [11] ***(Fig. 1).*** Over the 2013-2017 period, the renewable energy mix in Romania has been diversified. Of all types of renewable energy, the highest increase was registered by the solar power by over 800% even if, in terms of contribution to the renewable energy mix, is at the bottom of the list (2%) after hydropower (23%), wind (12%), only followed by biomass (1%)[3]. The structure of the electricity production displays almost the same situation, i.e. in 2018, hydro power had the highest share (29%) followed by coal (25%), nuclear (18%), natural gas (15%), wind (10%), photovoltaic (2%) and biomass (1%)[4]. The solar energy has been included in the energy circuit since 2012 [12,13].

Under the rapid transformation and growth of the energy sector, understanding the impacts of the past, current and future renewable energy development projects is essential for preventing the resulted negative environmental consequences [4]. As a result, the current study is focusing on the regional differences of PV farms in terms of spatial distribution and associated environmental consequences in Southern Romania, an area with significant solar resources. Thus, the main objectives of the current study are to: (1) identify and map all PV farms in Southern Romania; (2) analyse and understand the underlying environmental features which drive the spatial differences of PV farms distribution and to (3) identify the key environmental consequences of PV farms.

The issues related to solar energy resources in Ukraine are being investigated at the Ukrainian Hydrometeorological Institute, in particular the zoning of the territory of Ukraine according to the indexes of solar energy potential, the Atlas of energy potential of renewable and non-traditional energy sources was published [14-16]. In 2004, the Institute of Renewable Energy of NAS with a solar power department was established. A number of monographs have been published and the journal "Renewable Energy" is published

Methodology

The current study is focusing on PV farms, which through their footprint have proved to have more significant direct impacts on the environment [6, 17-19] than the installations integrated into the existing built environment (e.g. roof-top PVs) [20], due to their scattered distribution and indirect relation to the environment components. The authors extracted PV fields from satellite images (Landsat 7 ETM and Landsat 8 OLI, 2018). The resulted spatial data was correlated and completed with the records provided by the Romanian Transmission and System Operator (TSO) Transelectrica (e.g. installed power of each PV field, type of PV). Finally, in order to

[1]https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

[2]https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

[3]http://version1.sistemulenergetic.ro/

[4]http://statistici.insse.ro/shop/

highlight the environmental consequences of PV farms, several statistical and spatial indicators have been performed: the share/surface of PV farms at County level; the share of PV farms of each land use/cover category (based on CORINE Land Cover 2012); distance to forests, waters, protected areas (SCI, SPA); share of PV farms of main soil types. The resulted statistics enabled the authors to identify the existing and the potential environmental impacts of PV farms on specific environmental components [13].

Study area

The study focuses on Southern Romania, the area with the highest solar energy potential and the largest number of PV farms in the country. It overlaps four Development Regions – NUTS 2 (South-East, South-Muntenia, Bucharest-Ilfov, and South-West Oltenia), territorial-statistical entities without legal personality, which are subdivided into two-tier administrative structures: County (NUTS 3) and communes, towns and municipia (Local Administrative Units - LAU). From geographical point of view the study area has a stepwise distribution of the landforms from the north, north-east to the south and east: from mountains, hills and plateaus to plains and the Danube Delta. It covers a significant share of the Southern and Curvature Carpathians, small shares of the Western Carpathians, the southern part of the Moldavian Plateau and entirely the Getic and Curvature Subcarpathians, the Getic Piedmont, the Romanian Plain, the Dobrogea Plateau and the Danube Delta (the map is created).

Overall, the area is spanning over 101,200 km^2 (42.5% of the territory of Romania), covering extended agricultural lands (mainly arable land – 48%) followed by forest areas (21%), natural grassland (8%), urban areas (6%), wetlands (3%) and water bodies (3%) ***(Fig. 2).***

The climate is temperate-continental, with submediterranean (west), to transitional (centre) and aridity (east) influences [21]. It displays all climate regions in relation to the unfolding of all major relief forms from north to south and south-east (from the high Carpathian Mountains to the littoral), each with its own specific features [22]. Thus, the mix of the environmental conditions (e.g. climate, topography) supports the development of PV farms in large number, especially in the Romanian Plain and the Getic Piedmont. The authors identified and mapped 145 photovoltaic farms built between 2010 and 2017 covering a total area of about 1,643 hectares unevenly distributed throughout the study area, with a higher concentration in Prahova (21) and Giurgiu (20) Counties, followed by Dolj (17), Olt (15) and Dâmboviţa (15) Counties. At Development Region level, the spatial distribution shows that South-Muntenia (79) and South-West (44) Development Regions concentrate the highest number of PV farms (the map is created).

On relief units, a significantly large share of PV farms are grouped in the Romanian Plain (113 which concentrate 78% of the total number (map compiled) in relation to the higher solar energy potential and the flat relief which makes their installation and use more facile. In addition, the deficient land management and the national policies favoured the extended valorisation of the territory for solar energy production [13]. The lowest shares are located in the Subcarpathians and the Dobrogea Plateau totalling 13 PV farms (9%). Even though Dobrogea Plateau has a high potential in terms of sunshine duration (2300 h/year), it only amasses 4% of the power plants, due to the greater wind potential which is highly exploited. The installed power of the PV farms is generally low; 66% of the installations produce less than 3 MW, of which 29% below 1 MW. Larger systems (over 9 MW) cover only 15% of the territory, most of them located in the South-Muntenia and South-West Development Regions (the map is created).

Key environmental consequences of photovoltaic farms in Southern Romania

Although providing clean and sustainable energy sources in comparison to the conventional energy sources [17], the implications of PV farms could be either positive (e.g. use/reuse of degraded land) or negative (e.g. pollution, land degradation) [9, 10, 13]. In general, the environmental consequences of PV farms may differ depending on their evolution stage (e.g. construction, operation, decommission) in relation to the building activities and the related infrastructure [17, 20].

The impact of PV on ***land use/cover*** depends on a variety of factors (e.g. topography, surface, land use type) which might further lead to land transformation and/or land occupation [23, 24. Among all land use/cover categories, agricultural land is extensively used for placing the solar installations, followed by shrub land, pasture/hay and grass/herbaceous [6, 7].

In the study area, the main land use category covered by the photovoltaic panels is agricultural

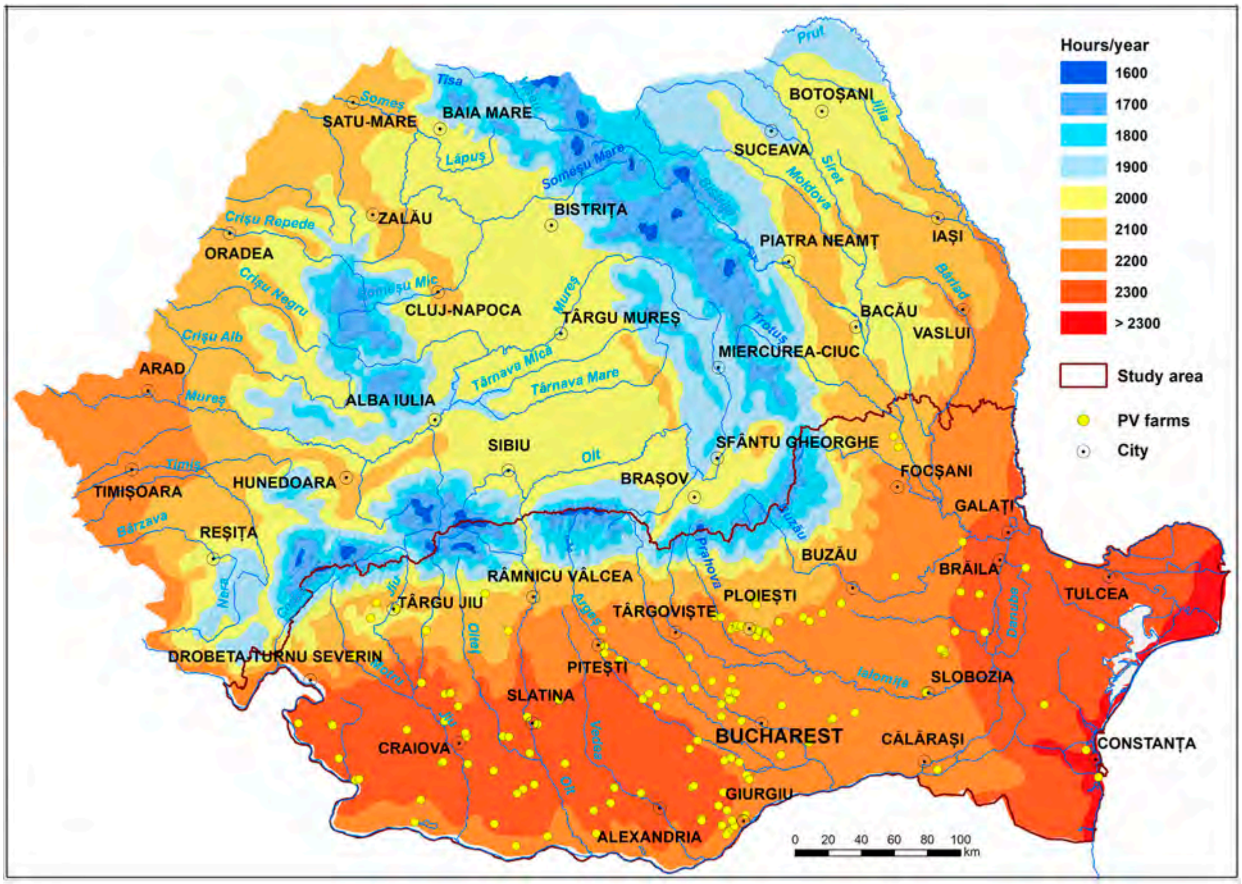

Fig.1. Sunshine duration and PV farms distribution in the study area

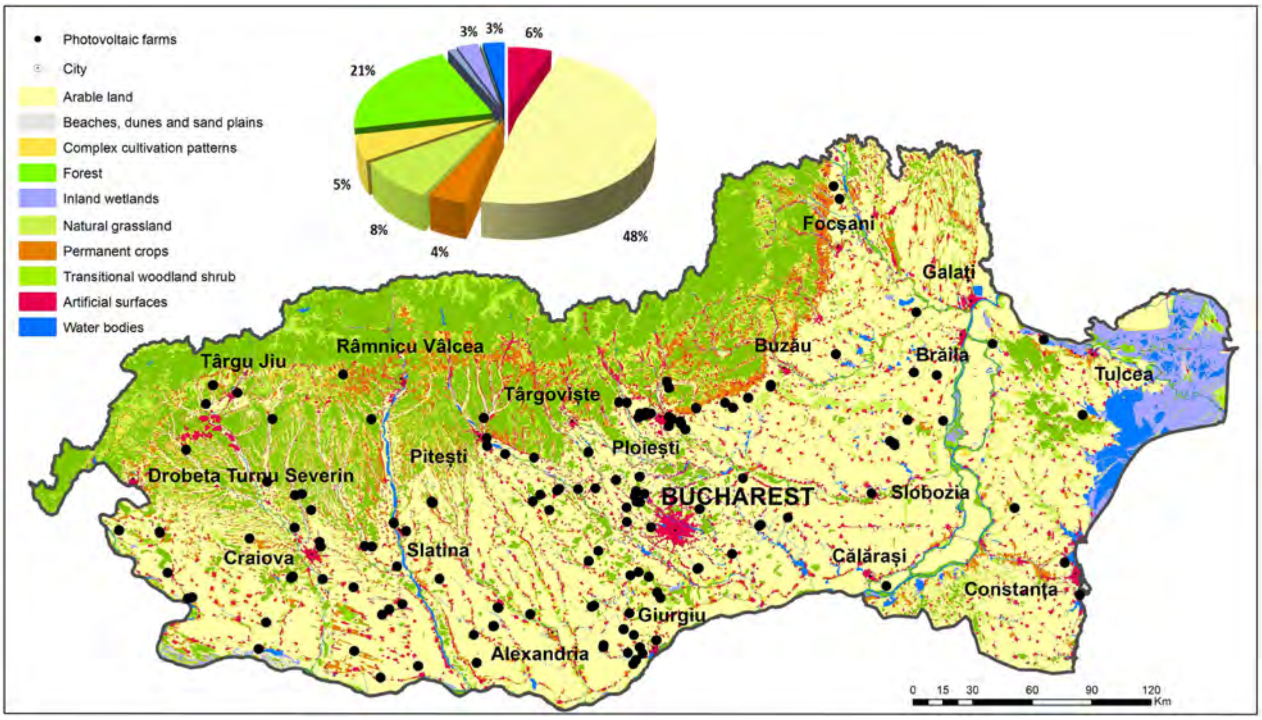

Fig. 2. The spatial distribution of PV farms on land use/cover in Southern Romania based on CORINE Land Cover 2012

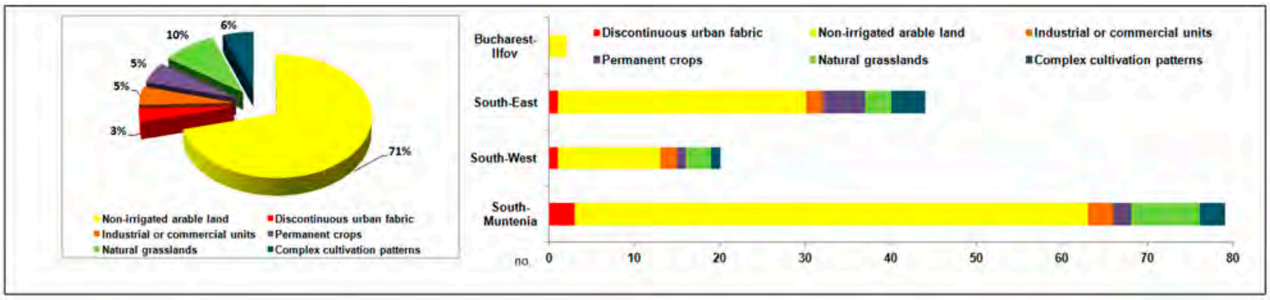

Fig. 3. PV farms distribution in relation to land use/cover (CORINE Land Cover 2012)

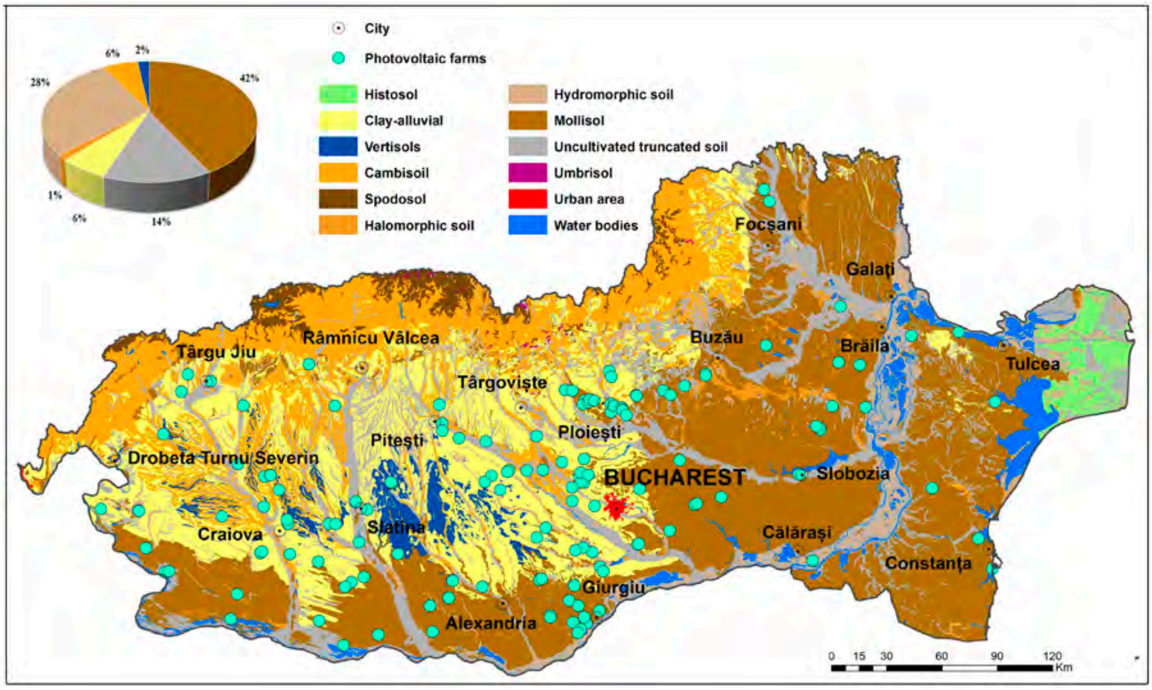

Fig. 4. PV farms distribution on main soil types

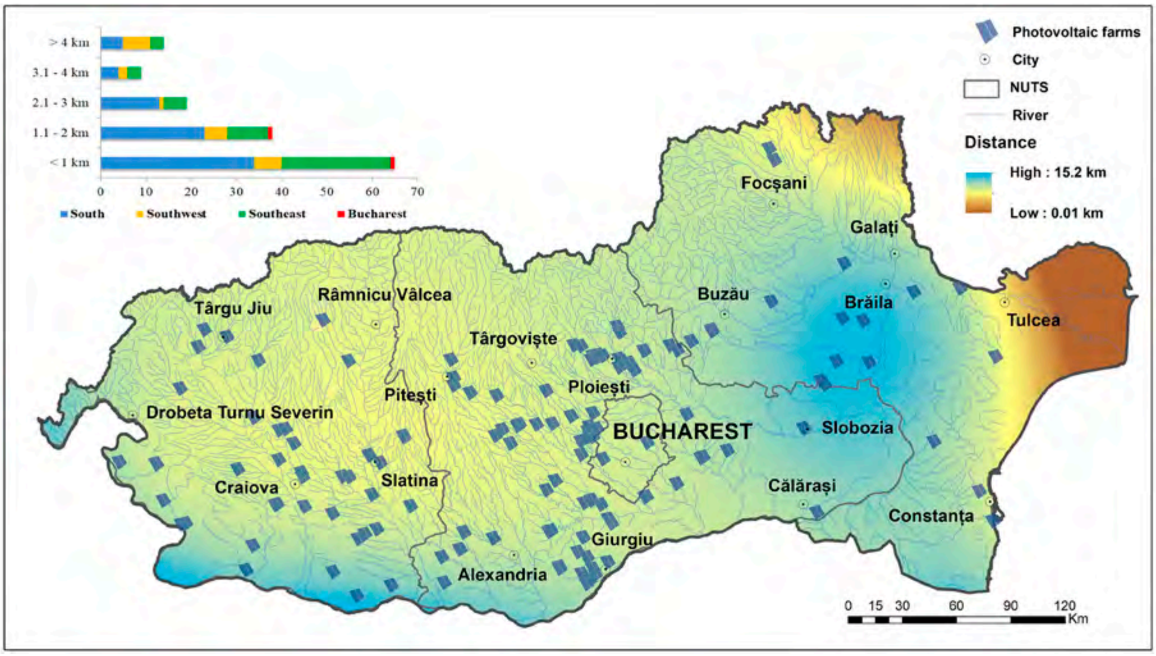

Fig. 5. Distance of PV farms to water bodies

land (71% of its surface), of which non-irrigated agricultural land supports the largest number of PV farms (103) and in much smaller extent natural grasslands (14), permanent crops (8) and complex cultivation patterns (8). In terms of distribution at county level, the largest number of PV farms is found in Giurgiu, Prahova, Dâmbovița and Dolj counties, mainly on non-irrigated arable land. South-Muntenia and South-East Development Regions concentrate the highest shares of the PV farms, mostly on non-irrigated agricultural land (61%) and natural grassland (8%) ***(Fig. 3).***

The land use transformation driven by the PV systems installation is most likely to have significant impacts on ***soil*** quality and productivity, especially when installed on agricultural land (mainly arable) [17]. Thus, during PV farms installation, the removal of vegetation exposes soil to different processes (e.g. degradation, compaction). In addition, the changes in soil temperature, precipitation and evapotranspiration (soil moisture) may alter the carbon cycle in solar parks [25]. Moreover, depending on texture, silt and clay particles, soil can be easily removed and transported by water or wind. This might cause degradation, as well as impacts on human health, biogeochemical or hydrologic cycle, sometimes leading to desertification [20].

With a total arable land of 48%, in Southern Romania, two types of land use compete: agriculture and the construction of photovoltaic panels. 70% of the PV plants are located on high fertile land, namely mollisols and alluvial soils, mainly in the Giurgiu (18), Prahova (12), Olt (11), Dâmboviţa (10) and Teleorman (9) counties, grouped in South-Muntenia and South-East Development Regions. Only 14% of the PV plants are located on uncultivated or degraded land (e.g. erodisols, pelisols, solonetz), especially in Prahova and Dolj counties ***(Fig. 4)***.

The impact of PV farms on ***water use and quality*** could be two-folded: related to water extraction to clean the PV installations [20] and to the chemical substances used in the process of washing the panels, leading to the infiltration of the contaminated waters into the soil and into the phreatic layer, as well as into the nearby rivers. As a result, the proximity of water sources is an important indicator which shows the possibility of the hydrological system of being polluted by the thermal or chemicals discharges [13]. In the study area, most of PV farms are located close to the river network (44.8% within less than 1 km and 26.2% between 1 and 2 km) which might negatively impact the quality of water bodies because of the pollutant substances used to maintain the photovoltaic panels. In the South-Muntenia Development Region, which concentrates the largest number of PV farms, 43% of the panels are located within less than 1 km from a water sources and 72.2% within less than 2 km. A significant percentage is also found in the South-West Development Region, where 63.6% of the panels are located within less than 1 km from the rivers ***(Fig. 5).***

The impacts of PV farms on ecosystems are

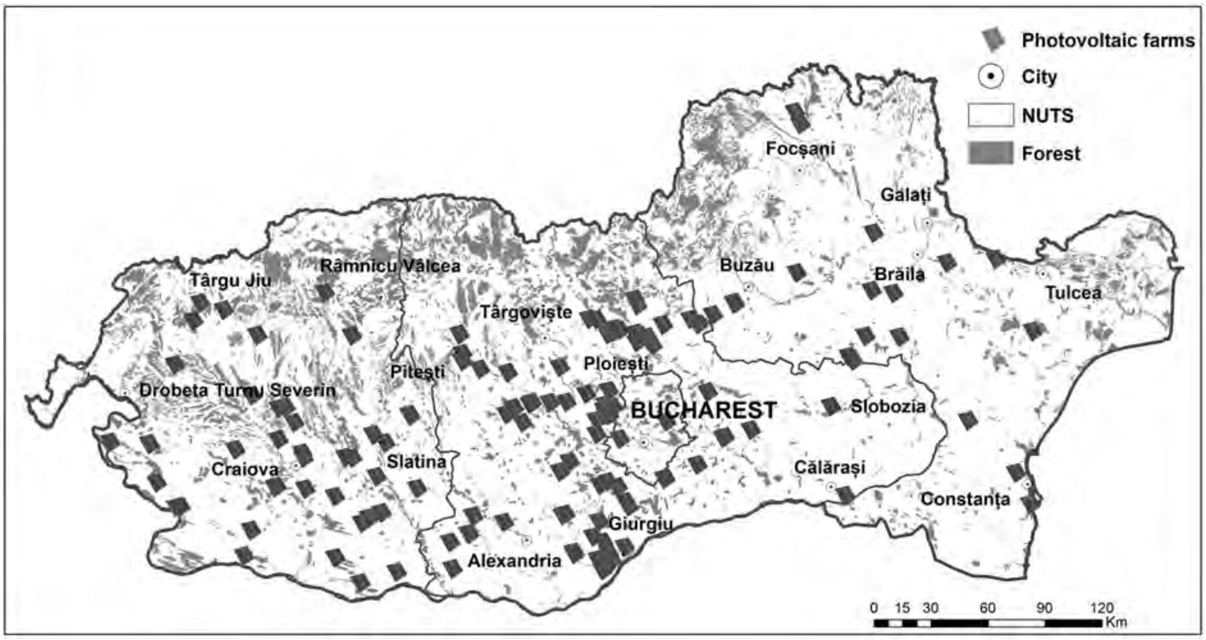

Fig.6. Distance of PV farms to forests

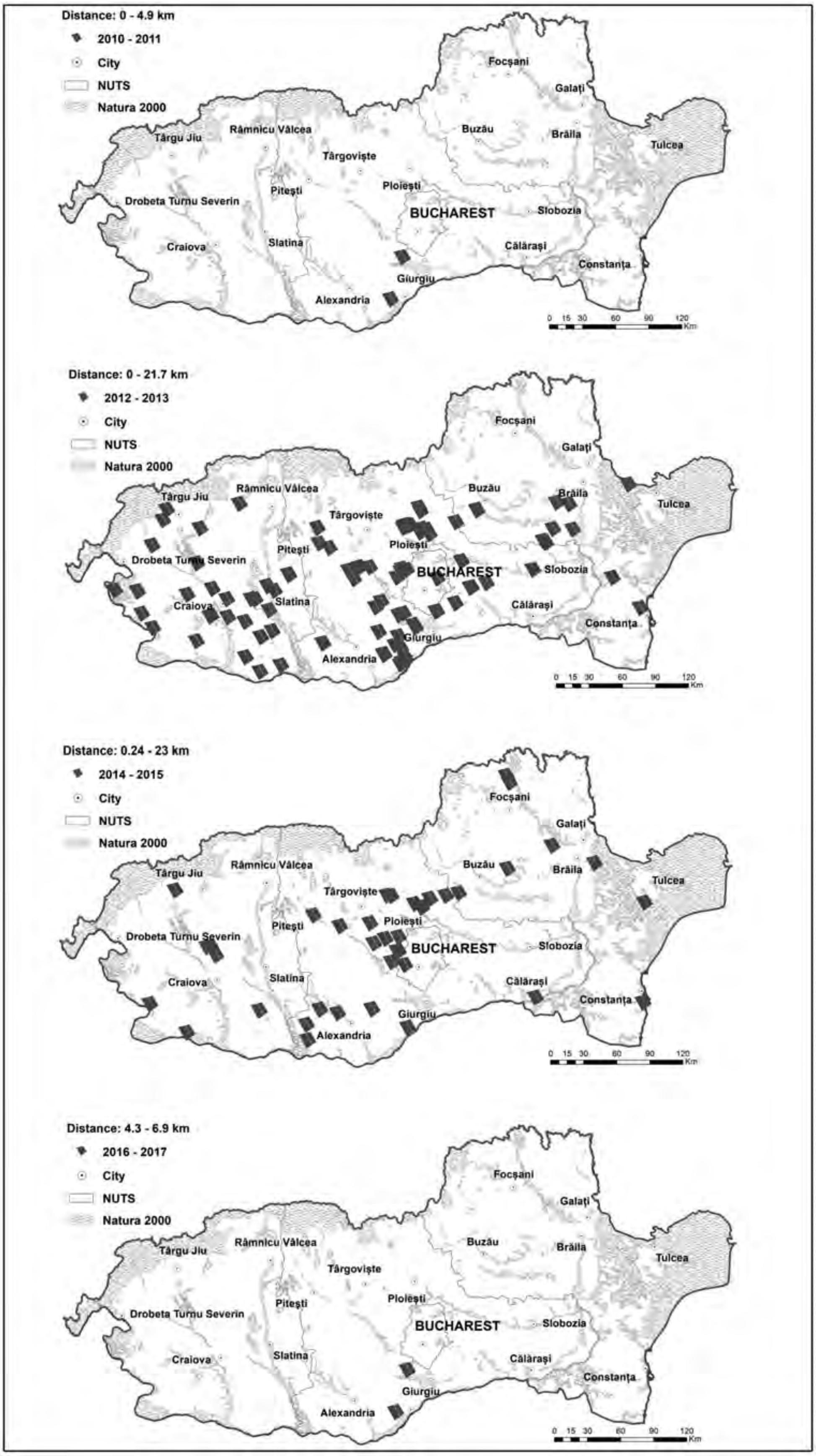

Fig. 7 Distance of PV farms to Natura 2000 sites

related to the fragmentation, change or loss of habitats that might occur following the installation and implementation of solar energy infrastructure [26], or to the proximity to sensitive or valuable ecosystems (e.g. forests, protected areas) [13]. In the study area, 32.4% of photovoltaic plants are located within less than 1 km and 70.3% within less than 2 km to forests. Generally associated with the development of road infrastructure, the proximity of PV farms to ***forests*** has negative consequences to ecosystems, through fragmentation and sometimes the destruction of habitats. The South-Muntenia and South-West Development Regions concentrate the largest forest-covered areas; 77.2% of the photovoltaic panels are located within less than 2 km from forests, mainly in Arges, Vâlcea, Prahova, Gorj and Dâmbovița counties. ***(Fig.6).***

The impacts of PV farms on ***protected areas*** (Natura 2000 sites) are generally driven by the ecological footprint (i.e. areas directly transformed or impacted by the PV installation) where the vegetation is cleared and soils typically graded [20, 26] with potential significant impacts on habitats and biodiversity. Bird species are the most affected by the solar systems through collision-related mortality (direct collision with heliostats) and solar flux-related mortality (burning from exposure to intense sunlight) [27, 28].

In Romania, the environmental consequences of PV farms were not taken into consideration since the beginning of their implementation. Thus, between 2010 and 2013, PV farms were built inside the Natura 2000 sites. Over the coming years, this situation has been improved and the distances to protected natural areas have increased from 800 m between 2014 and 2015 to 4.3 km in 2016 and 2017. Currently, there are 3 PV farms located inside protected areas: 2 inside Comana SCI and SPA (Giurgiu County) and 1 inside SPA Blahnița (Mehedinți County). Overall, most of PV farms are located at distance of over 5 km from protected areas. In particular cases (South-Muntenia and South-West Development Regions), PV farms are located within less than 5 km ***(Fig. 7)*** which is increasing the potential of negatively impacting habitats and biodiversity.

The proximity to ***settlements*** might be a positive aspect related to the diminished environmental impacts through the reduced distance of transporting materials or substances during installation or maintenance works. More than 31% of PV farms are located within less than 500 m from localities and 62.1% within less than 1 km. In the South-Muntenia and South-West Development Regions, 80% and 77% of PV farms, respectively are located within less than 2 km from the settlements.

The proximity to ***roads*** is an important indicator since it enables the access to PV farms, but it might also contribute to the potential fragmentation of habitats or ecosystems through access of the materials or substances necessary for the solar installations into different ecosystems, increasing the related impacts. In the study area, the distance to the main access roads is less than 1 km in the case of 99 PV farms and less than 2 km in the case of 130 PV farms. At the county level, the closest access roads are located in Prahova, Giurgiu, Dolj and Olt counties. Over 50% of PV farms are located in the South-Muntenia Development Region and nearly 40% of them are located within less than 1km from an access road. This is connected to the role of Bucharest as a regional attraction pole which favours the development of the road infrastructure in its proximity.

Another consequence of PV farms installation (together with the related infrastructure) is the fragmentation of landscape which is expected to reduce biodiversity through building barriers to the movement of species and their genes [20].

Discussions and Conclusions

Within the EU-28, increasing the share of solar energy has been one of the main achievements in terms of reaching the energy efficiency goal. Thus, the quantity of renewable energy produced increased by 64.0 % between 2007 and 2017, equivalent to an average increase of 5.1 % per year [29] exceeding the EU binding renewable energy targets set by the Renewable Energy Directive[5]. At national level, the Energy Strategy of Romania 2016-2030 set up among its key objectives the technical and economic measures targeting energy efficiency and the removal of the polluting impact of energy production and consumption through the use of renewable energy resources. As a result, the diversification of renewable energy sources has been registered. Solar power has become an important part of the national renewable energy system, underlined by the rapid and constant

[5] https://www.eea.europa.eu/data-and-maps/indicators/renewable-gross-final-energy-consumption-4/assessment-3

growth of solar energy producers (from one producer in 2009 to 576 producers in 2016) [13].

The current study revealed the two-faced consequences of solar energy in Southern Romania by identifying the current and potential impacts of PV farms and understanding their interactions with key environmental components. Although a clean and sustainable energy resource, solar energy proved to have some negative environmental consequences in relation to the installation and use of the solar systems. The study area has among the highest exploitable energy potential due to favourable biophysical factors, especially in the Romanian Plain. Here, the intensity of solar radiation exceeds 1350 kWh/m^2/year and the sunshine duration 2200 hours/year. South-Muntenia and South-West Development Regions concentrate the highest number of PV farms, mainly in Prahova, Giurgiu, Dolj, Olt and Dâmboviţa counties. The territorial expansion of PV systems in the recent years has led to an increased demand for land resources, mainly agricultural, bringing in significant changes in the land patterns and the withdrawal of high quality farmland [13]. This is also the case of the study area where an extended share of PV farms is located on agricultural land (71% on non-irrigated arable land). As a consequence, at legislative level, the Law 220/2008 for establishing the system to promote the production of energy from renewable energy sources is to be amended so that the installation of solar panels on agricultural land to be prohibited. On the other hand, the installation of solar systems has the potential of reclaiming degraded or abandoned sites in order to increase their economic value.

Given the increased accessibility, about 68% of PV farms were built at a distance of less than 1km from the road network and over 62% are located within less than 1km from localities. This situation can, on one hand, minimize the environmental effects due to the short distances for transporting materials or substances during installation or maintenance, but also lead to an increased impact on biodiversity and habitats through fragmentation due to road building. Over 71% of the PV farms are located at less than 2 km to the river network, thus exposing the water bodies to the potential thermal or chemicals discharges during maintenance works. Overall, the lands occupied by the solar power plants sum up to over >1600 ha. Although during the construction of the first PV farms in Southern Romania, the investments did not consider proper distances to natural areas (Natura 2000 sites or forests), in the following years the distances increased considerably. Thus, approximately 68% of the PV farms are located at over 1 km from forests, and 61% at over 5 km from protected natural areas.

Nevertheless, the extended use of solar renewable sources in Romania is an important part of its transition towards a green economy and in reducing the human impact on the environment, especially in the last years; about 88% of the photovoltaic power plants being built in 2013-2014. Thus, in 2010, Romania already has achieved the 2020 European Union's climate and energy targets. For the future, the expansion of solar farms has been identified as one of the key solutions for sustainable local development "especially in rural and isolated areas"[6] through employment and infrastructure opportunities.

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[6] https://www.eca.europa.eu/Lists/ECADocuments/SR18_05/SR_Renewable_Energy_EN.pdf

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