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TECHNICAL AND ECONOMIC DEVELOPMENT OF THE PHOTOVOLTAIC ELECTRICITY IN BULGARIA

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Abstract: The paper presents technical and economic data on the development of photovoltaic electricity in Bulgaria over the last 10 years. The mix of different types of conventional and renewable energy sources in the country's electricity system is shown. The changes in the installed photovoltaic capacities and the price of electricity generated by them for the studied period are shown in tabular and graphical form. The number of photovoltaic power plants and their distribution by groups of individual powers are given. Brief technical and economic data for some of the largest photovoltaic power plants in Bulgaria are provided. Data analysis shows a short period of rapid development of high-capacity photovoltaic power plants construction after the introduction of high feed-in tariff for the purchase of photovoltaic electricity, as well as the influence of the installed photovoltaic capacities on the market change of the feed-in tariff over time. Feed-in tariff cost decreases remarkably with the increase of the installed photovoltaic capacity and even shows removal tendency for larger-capacity photovoltaic power plants. Examples of the economic profitability of grid-connected and autonomous photovoltaic systems in Bulgaria are given. The analysis and conclusions of the paper could be useful in determining new government policies and setting new market conditions to promote the development of renewable energy sources in Bulgaria and other countries.

Keywords: photovoltaic electricity; electricity market; feed-in tariff; economic profitability; Bulgaria.

1. INTRODUCTION

Over recent years the price of electricity generated by photovoltaic systems has been continuously decreasing and they occupy a growing share of electricity generation worldwide. The specific share and timing of a country's photovoltaic electricity development depend on its energy policy and economic market conditions. Studies of these processes are important for the future development of photovoltaic energy worldwide [1–3].

The present study provides an example of the development of photovoltaic electricity in Bulgaria, which covers a time period prior and during the relatively short period of construction of the main photovoltaic power plants total power exceeding 1 GW, with the introduction of Feed-in Tariff (FiT), a motivating approach used in many other countries [4–6], and the subsequent period of the new installed capacities reduction due to market changes in the FiT value.

2. POTENTIAL AND CURRENT SHARE OF RENEWABLE ENERGY SOURCES IN BULGARIA

Bulgaria has taken an active role in the international efforts to help prevent climate change by supporting the concerted actions of the European Union and the wide-ranging package of measures in the energy sector. These measures give a new impetus to Europe’s energy security and support the EU’s ’20-20-20’ targets. The widespread use of renewable energy sources (RES) and the implementation of energy efficiency measures are among the priorities of the national energy policy and are complying with the objectives of the new energy policy for Europe [7].

The National Renewable Energy Action Plan (NREAP) of Bulgaria is the main instrument developed to ensure the achievement of the national renewable energy targets. The plan has been drawn up following the requirements of Directive

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2009/28/EC with the template adopted by Commission Decision of 30 June 2009. Under Directive 2009/28/EC, Bulgaria's mandatory national target for 2020 is a 16 % share of the energy from renewable sources in the gross final consumption of energy, including a 10% share of the energy from renewable sources in the consumption of energy in the transport sector.

The use of energy from renewable sources, in line with the requirements of Directive 2009/28/EC, is analyzed, promoted and reported separately along three lines:

– consumption of electricity – from wind, solar and geothermal energy, hydropower and biomass;

– consumption of energy for heating and cooling – solar and geothermal energy and biomass;

– consumption of energy from renewable sources in transport – biofuels and electricity produced from renewable sources.

The long-term implementation of the renewable energy policy is ensured by the national legislation which reflects and fully implements the requirements laid down by the European Parliament and the Council concerning energy generation from renewable sources.

The national policy on the promotion of energy generated from renewable sources has the following objectives: promotion of the development and use of technologies for the production and consumption of energy obtained from renewable and alternative energy sources; promotion of the development and use of technologies for the production and consumption of biofuels and other renewable transport fuels; diversification of the energy supply; environmental protection; creation of conditions for sustainable development at local and regional level.

The total technical potential of energy production from renewable energy sources in Bulgaria is about 4500 ktoe annually. The contribution of different sources is uneven (Table 1), the biggest share being hydropower (~ 31%) and biomass (~ 36%). Bulgaria's geographical location explains the relatively marginal role of wind energy (~ 7.5%), tidal and sea wave energy. However, the country has significant forestry resources and a developed agricultural sector as sources of solid biomass and raw material for biogas and liquid fuels. Until 2008, Bulgaria chiefly exploited the potential of hydroelectric energy and solid biomass, which is used primarily to heat households and public buildings. The production of electricity from wind and solar power plants is rapidly developing, and so is the use of solar energy for households hot water needs [8].

Table 1. Estimate potential of the renewable energy sources in Bulgaria as per an updated assessment for 2009.

Renewable source according to Regulation 1099/2008 for the energy statistics	Technically available potential
Hydro-power	1 290
Geothermal energy	18 (331 with the use of reinjection technologies.)
Solar energy	389
Tidal energy	Unspecified
Wind energy	315
Solid biomass	1 524
Biogas	280
Liquid fuels	366
Total	4 495

Table 2 presents data from the energy enterprises connected to the transmission network provided by Electricity System Operator of Bulgaria (ESO) for the installed capacity and the net generated electricity, and their shares by power plant type in 2017 (Table 2 and Figure 1).

Information about the real-time change of the generated electric power by type of the power plants and the electric load of Bulgaria's electricity system can be viewed on the ESO website: www.eso.bg, in the menu "Dispatching » Operational Data » EPS real-time generation and load" – Figure 2.

The connection of renewable energy plants to the grid is subject to the provisions of the general legislation on energy. The use of renewable energy for heating and cooling is promoted through a subsidy from the European Regional Development Fund, several loan schemes and an exemption of building owners from property tax. In Bulgaria, the main support scheme for renewable energy sources used in transport is a quota system. This scheme obliges companies importing or producing petrol or diesel to ensure that biofuels make up a defined percentage of their annual fuel sales. Furthermore, biofuels are supported through a fiscal regulation mechanism. The policies on Electricity, Heating and Cooling, and Transport aim at promoting the development, installation and usage of RES-installations in Bulgaria. There is a professional training program for RES-installers as well as a building obligation for the use of renewable heating and the exemplary role of public authorities. [11]

Table 2. Installed capacity and net generated electricity in Bulgaria for 2017 [9]

Power Plant type	Installed capacity		Net electricity generated	
	MW	Share, %	MWh	Share, %
1. Nuclear	2 000	16.6	14 718 368	36.2
2. Thermal - Lignite coal	4 119	34.1	17 605 902	43.3
3. Thermal - Black and brown coal	362	3.0	246 111	0.6
4. Thermal - Gas	563	4.7	1 609 514	4.0
5. Hydro, including:	3 204	26.5	3 395 131	8.4
5.1. Pumped Storage generation	1 399	11.6	899 639	2.2
5.2. Pumped Storage pumps	933	7.7	647 485	1.6
6. Renewable Energy including:	1 822	15.1	3 054 993	7.5
6.1. Wind	701	5.8	1 414 564	3.5
6.2. Photovoltaic	1 043	8.6	1 325 472	3.3
6.3. Biomass	78	0.6	314 956	0.8
Total	12 070		40 630 018	

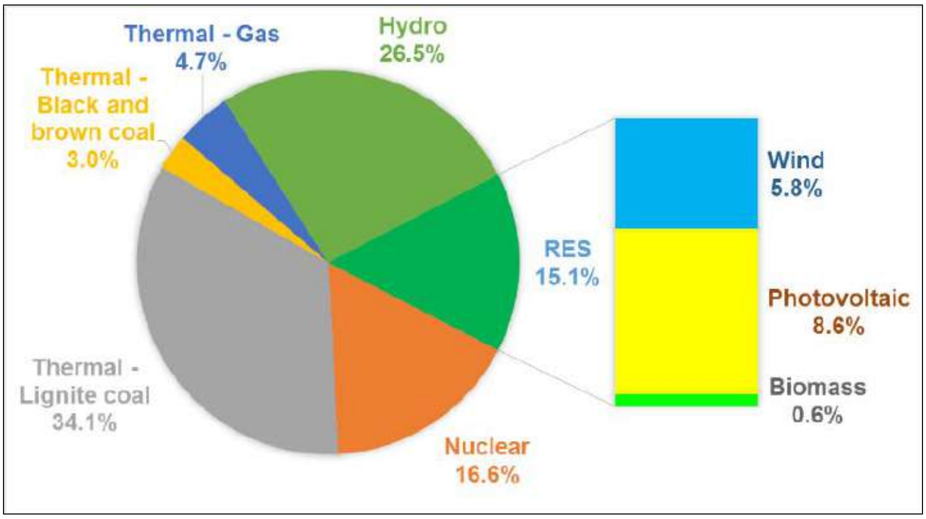

Figure 1. Installed capacity shares by power plant type in Bulgaria for 2017

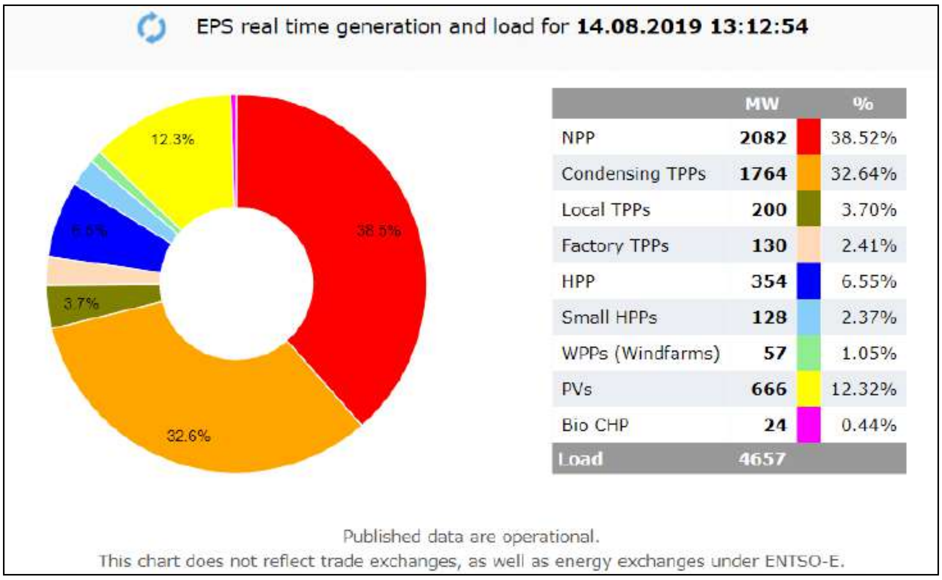

Figure 2. Real-time generation shares by power plant type and electricity system load in Bulgaria [10]

In Bulgaria, electricity generated by renewable sources is mainly promoted through a feed-in tariff. The Act on Renewable Energy Sources (ERSA) is the statutory basis for the feed-in tariff, which is the main element of the Bulgarian support system. The ERSA also establishes an obligation to purchase and dispatch electricity from renewable sources. Plant operators are contractually entitled against the grid operator to the purchase and transmission of all electricity from renewable sources supplied (art. 18 par. 1 item 2 ERSA). The amount of tariff is determined annually by the Energy and Water Regulatory Commission (art. 32 par. 1 ERSA). The FiT and the purchase obligation apply to power purchase agreements (PPAs) signed for projects implemented before the achievement by the Republic of Bulgaria of the RES end consumption mandatory targets under the National Renewable Energy Action Plan. The Energy and Water Regulatory Commission (EWRC) regulates the electricity selling price at the wholesale market and the FiT at which the RES producers sell electricity to suppliers [11].

Measures to encourage the use of RES to produce electricity have led to a 2-fold increase in its share of the total electricity generation over the past 10 years, which is already approaching about 20% – Figure 3.

Bulgaria ranks 11-th in the European Union by specific installed photovoltaic power per capita with 144.8 W/inhabitant and 1390 GWh electricity production from solar photovoltaic power in 2017 [12].

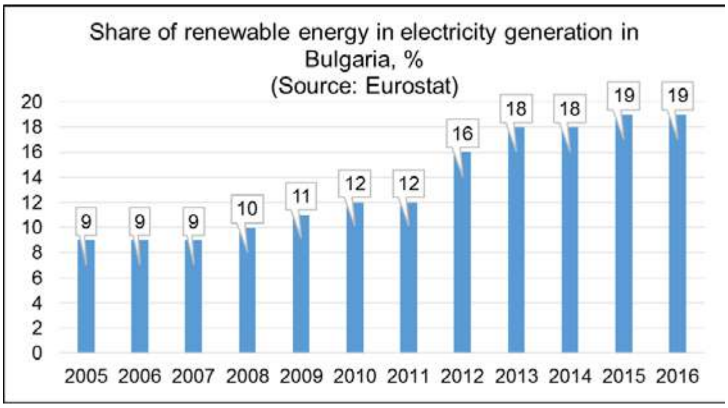

Figure 3. Change in the annual share of electricity produced from RES in Bulgaria

3. ANALYSIS OF THE DEVELOPMENT OF THE PHOTOVOLTAIC ELECTRICITY IN BULGARIA.

The real accelerated development of the photovoltaic electricity in Bulgaria begins with the introduction of the FiT in 2008. EWRC updates the FiT in the middle of each year [13], based on photovoltaic electricity purchased in the previous year and the current market conditions – Table 3 and Figure 4. When introduced in 2008, FiT was about five times higher than the average price of electricity for households and industry, for all types of photovoltaic power plants – Tables 3 and 4. This high price has led to significant investing in design and building of a large number of photovoltaic power plants in a short period. For only 2 years between 2011 and 2013, about 1 GWp of photovoltaic power was put into operation (Figure 5), significantly increasing the share of electricity production from RES. This, in turn, has led to an increase in the price of electricity and the necessary funding to cover FiT is obtained by increasing the RES penetration in the cost of electricity for the household and the industry. Finally, this resulted in a strong reduction of FiT and its separation according to the type of photovoltaic power plant – Table 3 and Figure 4.

The shape of the trend of change in the FiT in Bulgaria (Figure 4) is analogous to that in Germany [14], but the period for decreasing and establishing the FiT to a lower value is much shorter – about 3 years only.

Covering necessary financial resources of the obliged to buy the photovoltaic energy electricity supply companies is done by adding the “Green energy supplement” to the annual renewal of the electricity prices for the end-users. This “Green energy supplement” was visible in monthly bills for electricity of the end-users, reaching 5.68 EUR/MWh in 2013. The increase in this supplement has given the Bulgarian citizens the impression of a reason for the increase in the price of electricity. This has resulted in a reduced public approval for the development of photovoltaic energy and has caused public discontent, at the beginning of 2013, with electricity and other kind of government controlled energy prices rising, which has finally led to a review of the size and scope of the FiT implementation in the next years.

Table 3. Change in the years of the feed-in tariff for electricity produced by photovoltaics in Bulgaria, EUR/MWh

<table>
<tr><td colspan="2" rowspan="2">Installed power and type of photovoltaic power plants (PPP)</td><td colspan="14">Date</td></tr>
<tr><td>31.3. 2008</td><td>30.3. 2009</td><td>31.3. 2010</td><td>30.3. 2011</td><td>20.6. 2011</td><td>28.6. 2012</td><td>29.8. 2012</td><td>28.6. 2013</td><td>01.7. 2014</td><td>30.6. 2015</td><td>30.6. 2016</td><td>01.7. 2017</td><td>01.7. 2018</td><td>01.7. 2019</td></tr>
<tr><td rowspan="6">Ground based PPP</td><td>Up to 5 kWp</td><td>399.8</td><td>420.8</td><td>405.5</td><td>388.6</td><td rowspan="3">294.8</td><td rowspan="3">137.4</td><td rowspan="3">98.9</td><td rowspan="3">99.9</td><td rowspan="3">77.8</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>Over 5 kWp</td><td rowspan="9">367.1</td><td rowspan="9">386.0</td><td rowspan="9">372.2</td><td rowspan="9">357.4</td></tr>
<tr><td>Up to 30 kWp</td></tr>
<tr><td>Over 30 kWp to 200 kWp</td><td>290.1</td><td>133.3</td><td>96.2</td><td>97.7</td><td>73.3</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Over 200 kWp to 10000 kWp</td><td rowspan="2">248.3</td><td>121.2</td><td>87.6</td><td>90.1</td><td>68.5</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Over 10000 kWp</td><td>120.8</td><td>86.9</td><td>81.9</td><td>67.2</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="4">PPP on roofs and facades</td><td>up to 5 kWp</td><td rowspan="2">309.4</td><td rowspan="2">204.9</td><td>194.9</td><td>181.0</td><td>108.3</td><td>116.6</td><td>130.6</td><td>138.9</td><td>123.8</td><td>128.1</td></tr>
<tr><td>5 kWp to 30 kWp</td><td>148.3</td><td>145.3</td><td>104.3</td><td>108.2</td><td>109.4</td><td>118.2</td><td>105.3</td><td>106.7</td></tr>
<tr><td>30 kWp to 200 kWp</td><td>305</td><td>188.7</td><td>116.0</td><td>108.1</td><td>86.5</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>200 kWp to 1000 kWp</td><td>298.5</td><td>161.6</td><td>105.5</td><td>100.5</td><td>74.0</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
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Table 4. Change in the years of the average electricity price in Bulgaria, EUR/MWh [15]

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Industry	55.700	63.900	63.901	63.801	68.401	80.300	73.600	68.201	99.201	75.301
Households	71.101	82.301	82.303	82.599	84.598	92.401	83.203	94.200	95.601	95.504

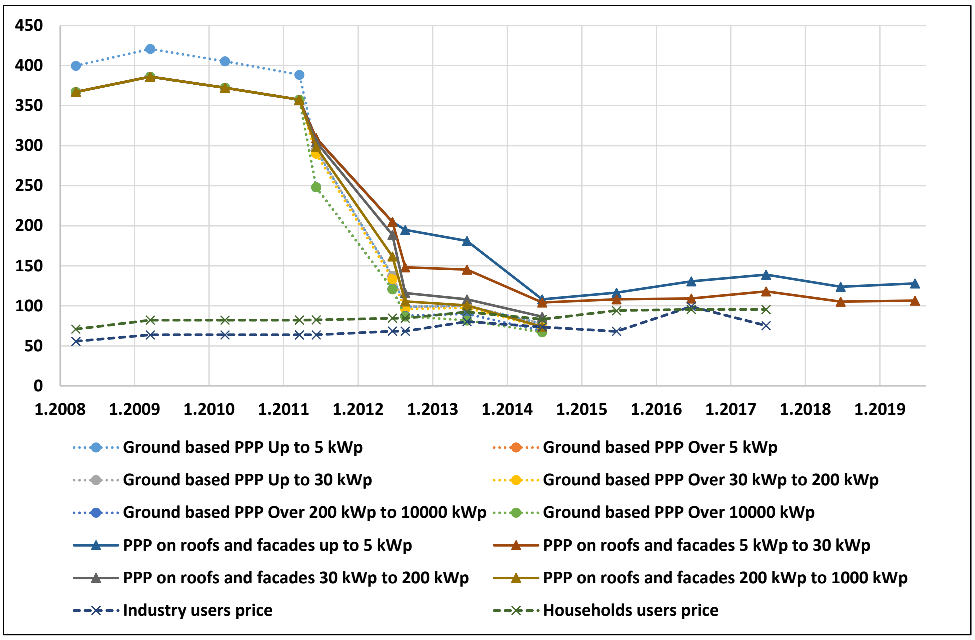

Figure 4. Comparison of the trends of the change of the FiT for different type of PPP and the average electricity price in Bulgaria for the last 10 - year period, EUR/MWh

In 2014, the FiT dropped out for all ground based and roof installed photovoltaic power plants power over 30 kWp, and FiT currently exists only for small roof and facade photovoltaic systems – Table 3 and Figure 4. This explains the comparatively small new installed capacities of photovoltaic systems in Bulgaria in the next years – Figure 5.

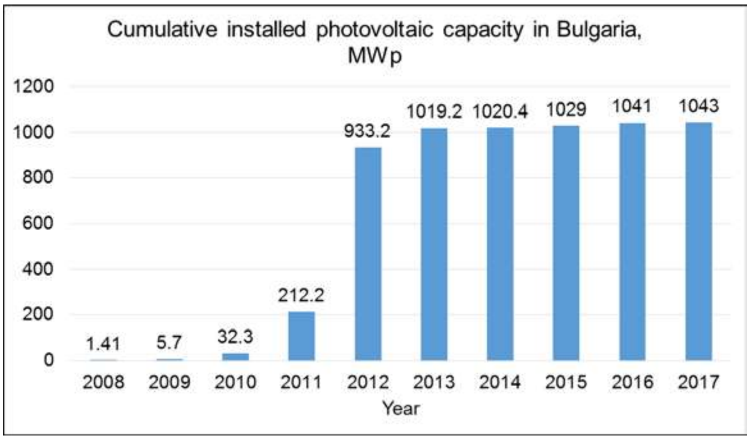

Figure 5. Amendment during the years of the cumulative installed photovoltaic capacity in Bulgaria, MWp

Another significant reason for the decrease in the rate of installation of new photovoltaic capacities in Bulgaria is their relatively large share of the total operating capacities of the Bulgarian electricity system. Reducing electricity consumption to below 3 GW in the months preceding summer, combined with the high performance during this period of the available 1 GWp photovoltaic systems and 0.7 GW wind power plants, may cause instability in the state's electricity system, due to the inability of the central dispatcher to reduce the power of the large nuclear and thermal power plants. Such a problem occurred in May 2013, was successfully resolved, but then an obligation was imposed on the large photovoltaic power plants operators to limit the instantaneous power of the photovoltaic power plant when ordered by the central national energy dispatcher. The implementation of this technique has been successful, but it provokes discontent among the owners of the controlled large photovoltaic power plants due to the inability to sell part of the electricity produced by their power plants. This shortcoming in the use of the unstable photovoltaic and wind power plants electricity production during the day is eliminated by a more flexible use of over 900 MW water pumping power plants available in Bulgaria, or the future construction of new energy storage systems.

4. TECHNICAL AND ECONOMIC DATA ABOUT THE PHOTOVOLTAIC SYSTEMS BUILT IN BULGARIA

According to the official register of the Agency for Sustainable Energy Development (SEDA) at the Ministry of Energy of the sites for production of energy from renewable energy sources, there are 1363 photovoltaic power plants registered in Bulgaria. [16] An analysis of their number distribution by the groups of different installed capacity sizes is shown in Table 5 and Figure 6.

The largest photovoltaic power plant has a power of 60.4 MWp, and the smallest officially registered one is power of 1 kWp.

Table 5. Distribution by number and single installed power of photovoltaic power plants in Bulgaria

Single installed power, MWp	Number	Total power, MWp
≤ 0.03	367	8.2
0.03÷0.20	661	69.8
0.2÷1	102	64.3
1÷10	226	683.1
>10	7	204.8

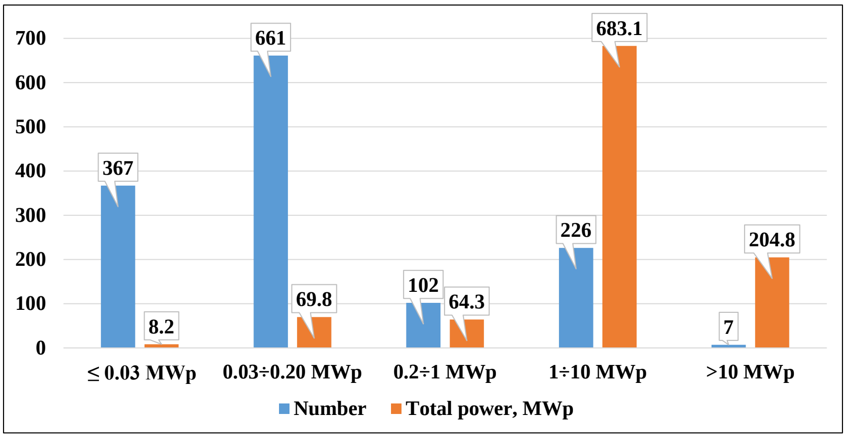

Figure 6. Comparison of the number and total capacity of the various sized photovoltaic power plants in Bulgaria

4.1. Largest photovoltaic power plants in Bulgaria

Karadzhalovo Solar Park (Figure 7) is the largest in Bulgaria with its installed power of 60.4 MWp. It has 214 000 polycrystalline photovoltaic panels, and cost 181.4 million EUR. It was completed in March 2012, after 4 months of construction [17].

Pobeda photovoltaic power plant (Figure 8), with a total installed capacity of 50 MWp, is the second largest in Bulgaria. It has 217 632 polycrystalline photovoltaic modules type NA C-Class 3bb with a single power of 225 Wp to 240 Wp connected to 86 inverters type PVS800-57-0500kW-A. The total area of the Pobeda photovoltaic plant is 1 016.814 acres. The value of the investment is 118.76 million EUR. It was put into operation in June, 2012 [18].

Cherganovo photovoltaic power plant (Figure 9) was initially planned to be with total installed capacity of 25 MWp, is now registered as 29.3 MWp, and is the third largest in Bulgaria. It has 124 896 HAREON polycrystalline modules with a single power of 230 Wp to 240 Wp connected to 50 inverters type PVS800-57-0500kW-A. The total area of the photovoltaic plant is 600.144 acres. The value of the investment is 61.285 million EUR. It was put into operation in June, 2012 [19].

Figure 7. The biggest photovoltaic power plant in Bulgaria – Karadzhalovo. [20]

Figure 8. The second largest photovoltaic power plant in Bulgaria – Pobeda. [21]

Figure 9. The third largest photovoltaic power plant in Bulgaria – Cherganovo. [21]

4.2. Examples of the roof and facade photovoltaic power plants in Bulgaria

Figure 10 shows a 132 kWp roof-mounted solar power plant in the industrial enterprise ZITA, in Rousse. The main components of the DC section of the power plant are mono-crystalline PV modules Sinski PV SPV180M-24, with nominal power of 180 Wp. The power plant consists of 840 modules, forming 2 plates, as follows: 1 plate with 520 modules with inclination of 5° and 1 plate with 320 modules with inclination of 11.2°, at Azimuth - 10.4°. Module surface area is 1072 m^2. The generated electricity is fed to 12 inverters Sunny Mini Central SMA SMC 11000 TL model and to each inverter 5 strings, consisting of 14 serially-connected modules are connected. The central monitoring and control device is Sunny Web Box. The 132 kWp roof-mounted solar power plant in industrial enterprise Zita, Rousse has been in operation since 10.05.2011. [22]

Three grid-connected photovoltaic roof-mounted systems for kindergartens (Figure 11) with capacities of 23.76 kWp, 21.96 kWp and 20.88 kWp with mono-crystalline PV modules, as well as systems with solar collectors for hot water, have been built in Gabrovo. They are equipped with monitoring systems containing SMA Sunny WebBox (including Ethernet interface), RS485 Module, SMA Sunny Sensor Box (including module temp sensor), PT100 Ambient Temperature Sensor and Wind Sensor.

Figure 10. Satellite photo (Google) of 132 kWp roof-mounted solar power plant in the industrial enterprise ZITA. [23]

Figure 11. 23.76 kWp grid connected PV system on the roof of the kindergarten „First June“ in Gabrovo

The first public building in Bulgaria with photovoltaic facade was built in Gabrovo – Figure 12. A 416 thin film photovoltaic panels Schuco MPE 85 AL 01 are mounted on the east, south and west facades of the building. The total installed power of the photovoltaic system is 35.19 kWp. The modules are grouped and connected to five single-phase inverters. To assure the autonomy of certain users in the building and to store the unused electrical energy produced by the photovoltaic plant, the inverters are connected to a common three-phase network electric board with a group of three inverters with a built-in charger (bi-directional off-grid inverter/charger). All reserved users are connected to this board. The off-grid inverters group is connected to a valve-regulated lead-acid (VRLA) battery array with an installed capacity of 57600 Wh. A data monitoring and storage system is also implemented, which includes Data Logger with RS485 interface for connection to inverters and LAN port for local or remote access to data via built-in WEB interface [24].

Figure 13 shows photos of the photovoltaic facade power plant on the farm building in Pazardzhik. The photovoltaic facade power plant capacity of 24 kWp is built by, in Bulgarian practice relatively low popular solar modules of copper-indium-gallium disellenide (CIGS) with 20% efficiency. The photovoltaic system is designed so that it is able to fully cover the energy needs of the farm machinery with a total output of 18 kW during the day [25].

Figure 12. First public building in Bulgaria with facade photovoltaic power plant

Figure 13. A 24 kWp CIGS photovoltaic facade power plant on the farm building [25]

4.3. Solar photovoltaic outdoor lighting in Bulgaria

The first solar lighting systems in Bulgaria were installed about 20 years ago in some of the university solar energy research centers in Bulgaria. Significant entry into practice of solar lighting systems occurred simultaneously with the boom of the biggest photovoltaic power plants installation in Bulgaria in 2012-2013. During this period, with funding from European programs, autonomous solar street lighting systems were built in several smaller Bulgarian municipalities and settlements: Municipality of Nikolaevo – 506 pillars, Kaynardja Municipality – 486 (Investment of 1.023 million EUR – Figure 14), Municipality of Straldja – 220, municipalities of Antonovo, Balchik, Sozopol, Pavlikeni and others.

Figure 15 shows photos of the photovoltaic lighting system in park in the town of Kardzhali. The pole systems consist of a photovoltaic panel, three light-emitting diode (LED) luminaries total power of 18 W, and a panel for battery and control unit. The control system allows remote adjustment of operating time, start and end time of switching on, depending on the length of the day. It is also possible to adjust the light output at different hours of the night [27].

Figure 14. Solar photovoltaic lighting in villages in Kaynardja municipality [26]

Figure 15. PV-LED lighting of a park in the city of Kardzhali [27]

5. ECONOMIC PROFITABILITY OF THE PHOTOVOLTAIC SYSTEMS IN BULGARIA

5.1. Economic profitability of the grid-connected photovoltaic power plants

Since the beginning of the development of photovoltaic electricity in Bulgaria, the economic profitability of the grid-connected photovoltaic power plants has been guaranteed by different kinds and single installed power of the plant (Table 3 and Figure 4). The FiT determination by EWRC takes into account following technical and economic parameters for roof and facade systems in 2018 [13,28]:

– Investment costs per kWp of: 1 334 EUR/kWp for systems with power up to 5 kWp, and 1 168 EUR/kWp for power from 5 kWp to 30 kWp;

– Operating costs - costs for environmental protection, materials, etc., costs related to the production process: EUR 35.24/MWh for systems power up to 5 kWp and EUR 27.42/MWh power from 5 kWp to 30 kWp;

– Useful life of the assets - 20 years;

– Operating cost inflation - 2%;

– The average annual plant working time is 1 302 hours, which equals 1 302 kWh/kWp net specific production;

– Weighted average rate of return - 7%.

With decreased prices for the construction of photovoltaic power plants over last years and largely increased prices of electricity for the industry in Bulgaria, a new trend is emerging- to build PV power plants in industrial enterprises for their own needs without signing contracts for the use of FiT. This trend shows that in Bulgaria the construction of photovoltaic power plants becomes a profitable investment without the need for FiT support, and this is a motivating beginning of a new period of increase in the use of photovoltaic systems.

In support of the above mentioned trend, variants of a real project for a 15 kWp photovoltaic power plant on the roof of an industrial building are shown below. The PPP has the following component prices:

– SMA Sunny Tripower 15000TL 2 inverter - 4 612 EUR;

– Photovoltaic Panels Canadian Solar Inc. CS6X-260P 260W - 114 pieces - 16 658 EUR;

– Constructions, installation and cabling - 1 738 EUR.

The total cost of the photovoltaic system is EUR 23 008.

For comparison, two variants are considered - a photovoltaic plant using FiT and a plant for enterprise own needs. Data for the input and calculated technical and economic parameters for the two project variants are shown in Table 6. The analysis of the results shows that, despite a higher cost of the FiT compared to the price of electricity for industrial consumers, due to the additional costs and fees for a contracted FIT connection to the grid, the industrial enterprise's own use variant is more financially profitable in this case.

Table 6. Economic comparison of the variants of a roof-mounted photovoltaic power plant using FiT and a plant for industrial enterprise own needs

Parameter	Variant using FiT	Variant for own needs
Estimated annual electricity production, MWh / year	37 505	37 505
Price of electricity, EUR / MWh	104.8	92
Cost of construction of the PPP, EUR	23 008	23 008
Cost of joining to the grid, EUR	511.3	-
5% Security Fund, EUR / year	196.5	-
Electricity meter fee, EUR / year	58.3	-
Transfer and access fee, EUR / year	429.5	-
Balancing fee, EUR / year	122.7	-
Total annual income, EUR / year	3 124.0	3 451.7
Payback period, years	8	7
Profit for 20 years – Net Present Value, EUR	38 892.79	45 949.62

5.2. Economic profitability of the stand-alone photovoltaic systems

The period 2012-2013 of the installation of relatively small number of solar street lighting systems (see section 4.3.) was short, since, after the removal of additional grant funding, these systems were financially unprofitable in Bulgarian market conditions, due to low cost and availability of electricity in all settlements, as well as the disadvantages of the rechargeable batteries used. For example, following calculations can be made from the operation of the similar PV-LED system for external lighting at the Technical University of Gabrovo (Figure 16): from the solar power supply of a 20W LED luminaire for 1 year 20 W x 4100 hours = 82 kWh x 0.102 EUR/kWh = 8.36 EUR/year are saved. For the entire 5 year battery life 5 x 8.36 = 41.80 EUR are saved, which is not enough to buy a new battery priced 205 EUR, or five times higher than savings. The example shows that under current price conditions in Bulgaria, autonomous photovoltaic systems for street lighting using batteries are not economically profitable. In addition to the relatively low cost of electricity, main reason for this is the high cost and the low life of the battery technology used.

Figure 16. PV-LED system for external lighting at the Technical University of Gabrovo

Due to the reasons described, stand-alone solar lighting systems have been installed in Bulgaria over the last years mainly in places where power supply would be too complicated, or expensive – Figures 17 and 18, or in places where the lighting is used mainly during the daytime – in schools [29], in kindergartens, etc.

Figure 17. PV-LED systems for additional illumination of road signs and pedestrian walkways

Over recent years Bulgarian researchers have been conducting interesting research on the big potential of photovoltaic lighting projects for road tunnels [31,32,33], for which the time with maximum necessary adaptation luminance of the lighting system and the corresponding electric power needed matches with the maximum solar radiation at noon, and the maximum power of the photovoltaic modules, respectively.

Figure 18. Autonomous PV system for power supply of high-altitude mountain information center Tazha hut in National Park „Central Balkan“ [30]

6. CONCLUSIONS

Based on the research and analysis done in the paper, following main conclusions can be drawn.

Measures to encourage the use of RES to produce electricity in Bulgaria by introducing FiT have led to a 2-fold increase in its share of the total electricity generation over the past 10 years, which is already approaching about 20%.

Data analysis on the development of the photovoltaic electricity in Bulgaria over the years shows a short 2-year period of rapid building of the high-capacity photovoltaic power plants after the introduction of FiT for the purchase of photovoltaic electricity, which is 5-times higher than the average electricity price for end-users. Studies show a strong decrease in FiT with an increase of the installed photovoltaic capacity and even its removal for all ground-based and roofs installed photovoltaic power plants power over 30 kWp, and current FiT only for small roof and facade photovoltaic systems. This FiT dropping out explains comparatively small new installed capacities of photovoltaic systems in Bulgaria after 2013. Another reason for the decreased installation of new photovoltaic capacities is their relatively large share together with the wind power plants, in the total operating capacities of the Bulgarian electricity system, which may cause problems in its stability during the months preceding summer, with low electric load at relatively large capacities of nuclear and large thermal power plants, more difficult to be fast regulated.

The period 2012-2013 of installation of a relatively small number of solar street lighting systems was short, since, after the removal of the additional grant funding, these systems were financially unprofitable under Bulgarian market conditions, due to low cost and the availability of electricity in all settlements, as well as the disadvantages of the rechargeable batteries used. New stand-alone solar lighting systems have been installed in Bulgaria mainly in places where power supply would be too complicated or expensive, or in places where lighting is used mainly during the daytime – schools, kindergartens, etc.

With decreased prices for the construction of photovoltaic power plants over last years and largely increased prices of electricity for the industry in Bulgaria, a new trend is emerging- to build PV power plants in industrial enterprises for their own needs without signing contracts for the use of FiT. This trend shows that in Bulgaria the construction of photovoltaic power plants is becoming a profitable investment without the need for FiT support, and this is a motivating beginning of a new period of increase in the use of photovoltaic systems.

The analysis and conclusions of the paper could be useful in determining new government policies and setting new market conditions to promote the development of renewable energy sources in Bulgaria and other countries.

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ТЕХНИЧКИ И ЕКОНОМСКИ РАЗВОЈ ФОТОНАПОНСКЕ СТРУЈЕ У БУГАРСКОЈ

Сажетак: У раду су представљени технички и економски подаци о развоју фотонапонске струје у Бугарској у посљедњих десет година. Представљени су различити типови конвенционалних и обновљивих извора енергије у електросистему државе. Промјене у инсталираним фотонапонским капацитетима и цијена струје произведене од стране њих за истраживани период су показани у табеларном и графичком облику. Промјене у инсталираним фотонапонским капацитетима и цијена струје произведене у њима приказане су табеларно и графички. Представљен је број фотонапонским електрана и дата њихова индивидуална снага по групама. Обухваћени су кратки технички и економски подаци за неке од највећих електрана у Бугарској. Анализа података показује кратак период убрзаног развоја и изградње висококапацитетних фотонапонских електрана након увођења високе feed-in тарифе за куповину фотоволтажне струје, као и утицај инсталираних фотонапонских капацитета на промјену тржишта feed-in тарифе током времена. Цијена feed-in тарифе се изузетно смањује са повећањем инсталираног фотонапонског капацитета и чак показује тенденцију уклањања за фотонапонске електране већег капацитета. Наведени су примјери економске профитабилности фотонапонских система повезаних на мрежу и аутономних фотонапонских система у Бугарској. Анализа и закључци у раду могу бити корисни при утврђивању нове владине политике и успостављања нових тржишних услова како би се промовисао развој обновљивих извора енергије у Бугарској и другим земљама.

Кључне ријечи: фотонапонска струја; тржиште струје; feed-in тарифа; економска профитабилност; Бугарска.

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