TECHNO-ECONOMIC FEASIBILITY USE OF PORTABLE SOLAR IRRIGATION SYSTEMS[1]

Nataša Kljajić[2], Vesna Paraušić[3], Aleksandar Rodić[4]

Abstract

Stable production in the Republic of Serbia is limited by rainfall, which is on the one hand insufficient and on the other hand unevenly distributed throughout the growing season. Therefore, the introduction of irrigation in agricultural production is of great importance because it contributes to the increase in production volume, it improves the quality of crop yields and the economic effects of investments in production. Depending on climatic conditions and the conditions for production, up to 100% higher yields can be obtained by irrigation, while in very dry years up to two or three times higher.

Serbia is a member of the Energy community with international obligations regarding the use of renewable energy sources (pursuant to Directive 2009/28/EC on the promotion of the use of electricity from renewable sources). In accordance with that Directive and the Decision of the Council of Ministers of the Energy Community in 2012 (D/2012/04/ MS - ENZ) and National Renewable Energy Action Plan of the Republic of Serbia („Official Gazette of the Republic of Serbia", No. 53/13) a very ambitious and binding target was set for Serbia of 27% gross final energy consumption from renewable sources by 2020. A number of national legislative and policy documents point out that increased use of renewable energy sources is a main need and aim in order to improve agriculture and economic development of Serbia.

---

[1] Paper is part of the research projects: III-46006 - *Sustainable agriculture and rural development accomplishing the strategic objectives of the Republic of Serbia within the Danube region*; funded by the Ministry of Education and Science of the Republic of Serbia for the period of 2011-2016.

[2] Natasa Kljajic, Ph.D., Research Associate, Institute of Agricultural Economics, Volgina Street 15, 11060 Belgrade, Serbia

[3] Vesna Parausic, Ph.D., Research Associate, Institute of Agricultural Economics, Volgina Street 15, 11060 Belgrade, Serbia

[4] Prof. Aleksandar Rodić, PhDEE, Head of Robotics Laboratory, Vice president of the Institute Assembly, Mihailo Pupin Institute University of Belgrade Volgina 15, 11060 Belgrade

The implementation of solar panels that convert sunlight into electricity is recommended in order to use irrigation systems at affordable prices and save energy, that is, to start and operate the water pump at lower cost. This is particularly important for those areas that are suitable for agricultural production (which can not be intense in the true sense of the word without irrigation), where there is no electric grid, and there are water resources: wells, groundwater, streams, canals, rivers or lakes. Due to low operating costs during use, the solar pump units prove to be more cost-effective than the petrol engine only after the second year of use.

Keywords: *Renewable energy sources, portable solar irrigation systems, energetically, environmentally and economically sustainable agricultural production.*

Introduction

The limiting factor for the intensification of agricultural production is seasonal change in climate parameters, especially the schedule and amount of rainfall during the growing season. The only long-term way to combat drought is the introduction of irrigation in agricultural practices, as well as regular and mandatory measures. Occasional irrigation, limited to smaller areas in private hands, gave results in terms of high and uniform yields of quality fruit, which can easily be placed on the market. These positive individual experiences should be extended to the territory of entire Serbia, and thus improve the situation in agriculture, as well as the overall economic situation.

In order to use irrigation systems at affordable prices and save energy, that is, to start and operate water pumps at low cost, the authors recommend the use of solar panels, which convert sunlight into electricity. Accordingly, the paper discusses the use of renewable energy sources and mobile robotized solar power generators as new technologies in the implementation of irrigation in agricultural production in the Republic of Serbia through the techno-economic analysis of these devices, the capacity of devices and through the examples of their use in experimental fields in several localities where their efficiency and cost-effectiveness can be seen.

Starting and operating of irrigation systems based on the use of renewable energy sources is in line with international obligations regarding the use of renewable energy sources that Serbia, as a member of the Energy Community, took over („Official Gazette of the Republic of Serbia“, No. 62/06). Namely, in accordance with EU Directive (2009/28/Ezo promotion of the use of electricity from renewable energy sources) and the Decision of the Council of Ministers of the Energy Community in 2012 (D /2012/04/MS

- ENZ), and National Renewable Energy Action Plan of the Republic of Serbia ("Official Gazette of the Republic of Serbia", No. 53/13), a very ambitious and binding target was set for Serbia of 27% gross final energy consumption from renewable sources by 2020.

The basic characteristics of irrigation measures applied in Serbian agriculture

Irrigation can be widely applied and used for different purposes. In addition to its basic use that involves adding water to the soil in order to compensate for the amount of water required for normal growth and development of agricultural crops in conditions of insufficient rainfall or their unfavourable schedule during the vegetation period, it is also used for fertigation, prevention of frost damage, phytosanitary protection, soil desalination etc. (N. Kljajić, 2012).

Worldwide, irrigation has experienced strong development over the last century and irrigated land has increased from 50 to 250 million hectares, so that irrigated land accounts for about 40% of the world's food. 60% of the world food production in the future is projected to be done with the use of irrigation systems (S. Petković, 2003).

Irrigated agricultural production allows a wider variety of crops during the growing season, especially early vegetables and two harvests during the growing season per unit area. By using irrigation it is possible to obtain higher yields, crop stubble and intercrop, it has an effect on the structure of agricultural production, deadlines and norms of sowing, soil tillage, plant nutrition and intensification of livestock production. In this way safe and stable agricultural production, which excludes large variation, is ensured (N. Kljajić et all, 2011).

The Republic of Serbia has favourable climate, land and water resources for intensive agricultural production. However, stable production is limited by rainfall, which is either insufficient, or unevenly distributed throughout the growing season. Therefore, the introduction of irrigation in agricultural production is of great importance, and depending on climate conditions and the conditions for production, up to 100% higher yields can be obtained by irrigation, while in very dry years up to two or three times higher.

According to (Kljajić, 2014; Cvijanović et al., 2012), irrigation in the Republic of Serbia is below the real needs and real possibilities and does not meet the needs of stable and efficient agricultural production. If the state of irrigation in our country is observed through the total number of irrigation systems, and the area on which they are built and used, the conclusion is that neither its extent, its technical equipment, nor the level of use of irrigation systems are satisfactory (Potkonjak, Mačkić, 2010).

According to *Census of Agriculture in the Republic of Serbia (2012)*, farms (legal entities, entrepreneurs, family farms) irrigated 2,9% of utilized agricultural land in the Republic of Serbia, and 3,6% in Vojvodina region (Table 1). The dominant irrigation method in the Republic of Serbia is surface method (60,6%), and in Vojvodina region surface irrigation (38,7%) and drip irrigation (36,2%) are approximately equally represented. The dominant source of water used for irrigation in the Republic of Serbia is groundwater found in household wells (51,6%), followed by surface water outside the households (31,0%), while in the region of Vojvodina these two sources of water are equally represented. In the Republic of Serbia and the region of Vojvodina fields and gardens are predominantly irrigated, approximately 85% in the Republic of Serbia and 91% in Vojvodina.

Table 1. ***Irrigated area in the Republic of Serbia, Vojvodina region i Srem, agricultural 2011/2012 year***

	Number of farms	Irrigated area, ha	Utilized agricultural land (KP), ha	Irrigation percentage compared to KPZ (%)
The Republic of Serbia	71.947	99.773	3.437.423	2,9
Vojvodina region	7.385	58.251	1.608.896	3,6

Source: *Census of Agriculture 2012, Agriculture in the Republic of Serbia, book 1, Statistical office of the Republic of Serbia, 2013.*

Irrigation in Serbia has the following characteristics (Kljajić, 2014; Cvijanović et al., 2012):
- mainly applied to small areas, and therefore has little impact on the volume of agricultural production;
- It is used very extensively, since it is mostly treated as a supplementary measure in the stabilization of agricultural production (in terms of neutralizing the negative effects of drought);
- the basic conditions for the use of irrigation in terms of land consolidation and land reallotment etc. are not fulfilled.

Restrictions for greater use of irrigation in the Republic of Serbia are the following:
- The lack of organized infrastructure to solve the problem of water intake and provide water for crop irrigation;
- Due to the very poor maintenance of irrigation systems built in the past, a number of irrigation systems are neglected. Specifically, the liquidation (bankruptcy) of many agricultural conglomerates and agricultural enterprises

led to the destruction of their irrigation systems. Another problem is the failure of the privatization process in the agricultural sector, disordered and unresolved property relations and the like;

- The existing canal network (network of amelioration channels) cannot be used for both irrigation and drainage[5];
- Agricultural holdings lack funds for the purchase of proper equipment and irrigation devices.

In addition to addressing all of the above irrigation restrictions in Serbia, it is important to introduce the concept of „water users association" (abbreviated WUA) in the future construction of regional water supply systems and irrigation systems, considering the fact that it is precisely this association that should play a key role (responsibility, competence, ownership) in the maintenance and use of water supply system and irrigation. These associations work on a non-commercial and non-profitable basis and efficiently perform their tasks, such as irrigation system maintenance, drainage system management, maintenance of flood protection system, waste water disposal and treatment, supplying the population with water and the like. A large number of countries around the world are currently transmitting water management tasks from state agencies to participatory, independent, financially self-sustaining water users associations (Zorica Srđević, Bojan Srđević, 2008, p. 69). The trend is especially prevalent in the irrigation sector, where the responsibility for the effective operation and maintenance of the system transfers (delegates) to the association of farmers, as well as water users (Ibidem, p. 69). This approach is especially prevalent in the countries of Eastern Europe and Central Asia, where such associations previously responsible for irrigation and drainage system management, are now disbanded agricultural cooperatives.

Currently in Serbia there is no organized problem solving of some important issues that are a prerequisite for the formation of WUA, in terms of how it's done in a number of countries in the world (setting the institutional and legal framework of WUA; addressing issues related to measuring the amount of water consumed, if farmers will pay based on the amount of water used,

[5]The former dual use of parts of canal network Hydrosystem DTD for both irrigation and drainage, as well as some other channels outside the basic system, showed that there is an evident potential of this concept of water management related to the growth in agricultural production (Zorica Srđević, Bojan Srđević, 2008, p.70). Summary data for Vojvodina showed that according to the situation as of May 2003, about 83,000 ha of land can be irrigated from the drainage canals, with an investment of only 1,000 dinars / ha (Ibidem, p. 72). Dual systems require that the existing drainage canal network become fully functional (cleaning, reconstruction of existing channels, construction of canals and other activities in order to make the existing canal network effective).

defining the tariffs and subsidies; determining the ability and willingness of farmers to pay tariffs, etc.).

In order to use irrigation systems at affordable prices and save energy, and in order to respect the principles of sustainable development and energy efficiency in the future, great attention should be devoted to ***exploitation of solar panels and other renewable energy sources in the development of irrigation systems***. This is particularly important for those areas that are suitable for intensive agricultural production, in rural areas where there is no electrical grid, and there are water sources in the environment and favourable conditions for the development of agriculture, rural development, diversification of economic activities of farms and the like.Therefore, the rest of this paper deals with the use of renewable energy sources and mobile robotized solar power generators as new technologies in the implementation of irrigation in agricultural production in Serbia.

Legal and strategic framework for the use of renewable energy sources in Serbia and EU

By adopting the „Law on ratification of the Treaty establishing Energy Community between the European Community and the Republic of Albania, Republic of Bulgaria, Bosnia and Herzegovina, Republic of Croatia, Former Yugoslav Republic of Macedonia, Republic of Montenegro, Romania, the Republic of Serbia and the United Nation Interim Administration Mission on Kosovo“ („Official Gazette of the Republic of Serbia“, No. 62/06), Serbia became a member of the Energy community and accepted international commitment regarding the use of renewable energy sources (according to Directive 2009/28 / EC on the promotion of the use of electricity from renewable sources).

In accordance with the Directive 2009/28 / EC and the Decision of the Council of Ministers of the Energy Community in 2012 (D / 2012/04 / MS - ENZ), National Renewable Energy Action Plan of the Republic of Serbia for the period 2013-2015 („Official Gazette of the Republic of Serbia“, No. 53/13), a very ambitious binding target was set for Serbia, amounting to 27% of renewable energy sources in its gross final energy consumption in 2020.

National Renewable Energy Action Plan of the Republic of Serbia („Official Gazette of the Republic of Serbia“, No. 53/13), among other things, points out to the most important existing legislation relating to renewable energy sources, as well as the regulations that need to be adopted in the coming period, in accordance with Directive 2009/28 / EC. Important national legislation, which regulates and promotes the increased use of renewable energy sources and energy efficiency, is the following (listed chronologically):

- ***Law on Integrated Environmental Pollution Prevention and Control*** (Official Gazette of the Republic of Serbia No. 135/04);
- ***Law on Strategic Environmental Impact Assessment*** (Official Gazette of the Republic of Serbia, No. 135/04 and 88/10);
- ***Energy Strategy of the Republic of Serbia by 2015*** (Official Gazette of the Republic of Serbia number 44/05);
- ***Law on ratification of the Treaty establishing Energy Community between the European Community and the Republic of Albania, Republic of Bulgaria, Bosnia and Herzegovina, Republic of Croatian, Former Yugoslav Republic of Macedonia, Republic of Montenegro, Romania, Republic of Serbia and the UN Interim Administration Mission on Kosovo*** („The Official Gazette Republic of Serbia“, No. 62/06);
- ***Law on Ratification of the Kyoto Protocol*** („Official Gazette of the Republic of Serbia“ No. 88/07 and No. 38/09). The Kyoto Protocol, among other things, sets binding targets for the reduction of greenhouse gas emissions;
- ***National Sustainable Development Strategy*** („Official Gazette of the Republic of Serbia“, No. 57/08);
- ***Introduction of Cleaner Production Strategy in the Republic of Serbia*** („Official Gazette of the Republic of Serbia“ No. 17/2009), which defines "clean production" as a comprehensive preventive environmental strategy applied in production process, products and services, in order to increase overall efficiency and reduce risks to human health and the environment;
- ***Law on Nature Protection*** („Official Gazette of the Republic of Serbia“, No. 36/09 and No. 88/10), which regulates the protection and conservation of nature, biological, geological and landscape diversity;
- ***National Strategy on the Inclusion of Republic of Serbia into Clean Development Mechanism of the Kyoto Protocol for the Waste Management Sectors, Agriculture and Forestry*** („Official Gazette of the Republic of Serbia“, No. 8/2010);
- ***National Programme of Environmental Protection*** („Official Gazette of the Republic of Serbia“, No. 12/2010);
- ***Strategy on Science and Technological Development of the Republic of Serbia in period 2010-2015: focus and partnership*** („Official Gazette of the Republic of Serbia“ No. 13/2010). The Strategy points out that, among other things, the development of new technologies using

renewable energy sources and clean technologies with zero emission is one of the priority research topics in energetics and energy efficiency;

- ***The Energy Law*** („Official Gazette of the Republic of Serbia", No. 57/11, 80/11-correction, 93/12 and 124/12), which defines the objectives of energy policy; targets for use of renewable energy sources; manner, conditions and incentives for energy production from renewable sources and the like.
- ***National Strategy for Sustainable Development and Action Plan for period 2011- 2017*** („Official Gazette of the Republic of Serbia" No. 62/2011);
- ***Law on Public-Private Partnership and Concessions*** („Official Gazette of the Republic of Serbia", No. 88/11);
- ***National Strategy for Sustainable Use of Natural Resources and Goods*** („Official Gazette of the Republic of Serbia", No. 33/12), which among other things aims at "providing the conditions for sustainable use of natural resources and goods; reducing negative impacts of resource use on the economy and the environment; directing development towards sustainable production and the like."
- ***Law on Efficient Use of Energy*** („Official Gazette of the Republic of Serbia", No. 25/2013);
- ***Draft Energy Development Strategy of the Republic of Serbia until 2025 with indications until 2030.*** According to this document, the strategic development of energetics is based on establishing a balance between the production of energy from available sources, consumption of energy socially sustainable within the market and more efficient production and use of „cleaner" energy from renewable sources. In order to improve the energy system, among other things, 27% share of renewable energy sources in gross final energy consumption is planned. In order to preserve the environment, global energy tendency is to increasingly rely on renewable sources and less on exhaustible resources (principle of „cleaner" and more fuel-efficient energy production).

The use of renewable energy sources in irrigation and agricultural production in Serbia is in accordance with appropriate national legislation in the field of ***promotion and support of greater use of renewable energy sources in the agriculture sector.*** Important national documents in this field are the following:

- ***Law on Incentives in Agriculture and Rural Development*** („Official Gazette of the Republic of Serbia", No. 10/13). Support to investments in renewable energy sources is among the incentives and measures to enhance rural development, and programs for sustainable rural development which are implemented in order to improve and protect the environment.

- ***Strategy of Agriculture and Rural Development of the Republic of Serbia for period 2014-2024.*** („Official Gazette of the Republic of Serbia“, No. 85/2014). The strategy envisages that in 2024 Serbian agriculture becomes a sector the development of which is based on knowledge, modern technologies and standards, as well as that natural resources, environment and cultural heritage of rural areas are managed in accordance with the principles of sustainable development.

-***The Republic of Serbia IPARD Program for 2014-2020*** („Official Gazette of the Republic of Serbia“ No. 30/2016). Investments in renewable energy production will be supported through the following IPARD measures: (1) Investments in physical assets of agricultural holdings (quantified targets: the number of farms that implement modernization projects; the number of farms that invest in renewable energy production); (2) Investments in physical assets in processing and marketing of agricultural and fishery products (quantified targets: the number of companies that implement modernization projects; the number of companies that invest in renewable energy production); (3) Diversification of farms and business development (quantified target: the number of users who invest in renewable energy). In addition, investments in facilities for energy production from renewable sources will be supported only for personal energy consumption (the sale of electricity to the network is allowed within the limits of personal consumption). Bearing in mind the potential beneficiaries of IPARD II Fund of EU and the principle of co-financing measures (projects), it can be expected that it is precisely the interest to use these funds in the future that will encourage the consolidation and association of domestic producers in the agri-food sector through cooperative organizations. Implementation of IPARD II program will start after the completion of the accreditation process of IPARD II operational structure.

The concept of renewable energy sources and "green economy" (in sectors such as agriculture, fishery, forestry, construction, energy supply, industry, tourism, transport, waste and water management) is integrated in the legislative and strategic framework of the EU, where significant documents are the following:

- ***Directive 2009/28 / EC*** of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and repealing Directives 2001/77/EC and 2003/30/EC. In accordance with Directive 2009/28/EC binding targets are set for Member States of at least 20% share of renewable energy sources in gross final energy consumption by 2020 at the EU level. As part of the fulfillment of the defined share of renewable energy sources in gross final energy consumption, each Member State is required to ensure that the share of energy from renewable energy sources in all forms of transport in 2020 is at least 10% of the gross final energy consumption. Also, the improvement of energy efficiency is a key objective of the European Community, and the aim is to achieve 20% improvement in energy efficiency by 2020 (Directive 2009/28/EC, page 17).

- ***EUROPE 2020: A strategy for smart, sustainable and inclusive growth***, COM (2010) 2020 final, EC. The strategy, among other things, emphasizes smart and sustainable growth (developing economy based on knowledge and innovation and promoting a more resource efficient, greener and more competitive economy), as well as the principle of „Resource efficient Europe“. This principle involves the separation of economic growth from resource use, supporting the transition to low-carbon dioxide emissions, increasing the use of renewable energy sources, promoting energy efficiency and the like.

- ***EC Press Release, A resource-efficient Europe - Flagship initiative under the Europe 2020 Strategy*** (COM (2011) 21);

- ***The Roadmap to a Resource Efficient Europe*** COM (2011) 571, outlines how economies can be transformed into sustainable ones by 2050. It proposes ways to increase resource productivity and decouple economic growth from resource use and its environmental impact.

- ***EU biodiversity strategy to 2020*** (Our life insurance, our natural capital: an EU biodiversity strategy to 2020, the EC, Brussels, 3.5.2011, COM (2011) 244 final).

As for the use of renewable energy sources in agricultural production in the EU, it is important to note that the support of „green economy“ in the ***Common Agricultural Policy*** (CAP) implies the targeted assistance to rural development measures which promote environmentally sustainable agricultural practices, such as agro-environmental schemes, and improve compliance with environmental protection laws. Reformed Common Agricultural Policy for the period 2014-2020 for 28 EU member states[6], among other things, focuses on improving the competitiveness of agriculture by promoting innovation; environmental protection; sustainable management of natural resources; climate changes. The achievement of the objectives of

[6]The legal framework consists of four regulations that cover the sectors of rural development; horizontal issues, such as financing and control; direct payments to farmers and market measures (EU Regulation No.1305 / 13, 1306/13, 1307/1, 1308/13).

rural development is realized through six priorities of the Union, and support to renewable energy use is available through the fourth and fifth priority of the EU Rural Development (EU Regulation No.1305 / 13), which are „Restoring, preserving and enhancing ecosystems dependent on agriculture and forestry „(fourth priority) and“ Promotion of resource efficiency“(fifth priority).

Techno-economic analysis of mobile robotized solar power generators

Techno-economic feasibility and sustainability study of renewable energy in agriculture, with special emphasis on the use of portable (mobile) solar systems for energy production, is related to the exploitation of solar energy in the irrigation of agricultural crops in order to improve agricultural productivity and competitiveness, in both domestic and foreign markets (A. Rodić et all, 2016).

Water pumping for irrigation purposes on family farms in our country is mainly done by engine pumps and petrol or diesel driven generators. Very popular and widely used devices are DMB and Tomos diesel engine pumps. Also, Honda and Villager petrol engine pumps of different forces, mostly from 5-7 kW (3.7 to 5.5 KW), are quite often used.

Of all renewable energy sources, *stationary solar photovoltaic systems* are mainly used for agricultural purposes.They are placed in sunny locations and next to the agricultural area (gardens, fields, greenhouses, etc.). Windmills are used for irrigation to a lesser extent, and mostly in Banat and areas where there is constant air flow during the year.

Regarding the fact that in the Republic of Serbia family farms (they are in majority) possess arable land sometimes many kilometers away one from the other, stationary solar systems are not cost-effective solutions for this category of agriculture producers. For this reason, farmers prefer to opt for the purchase of motor units for irrigation compared to solar irrigation systems.

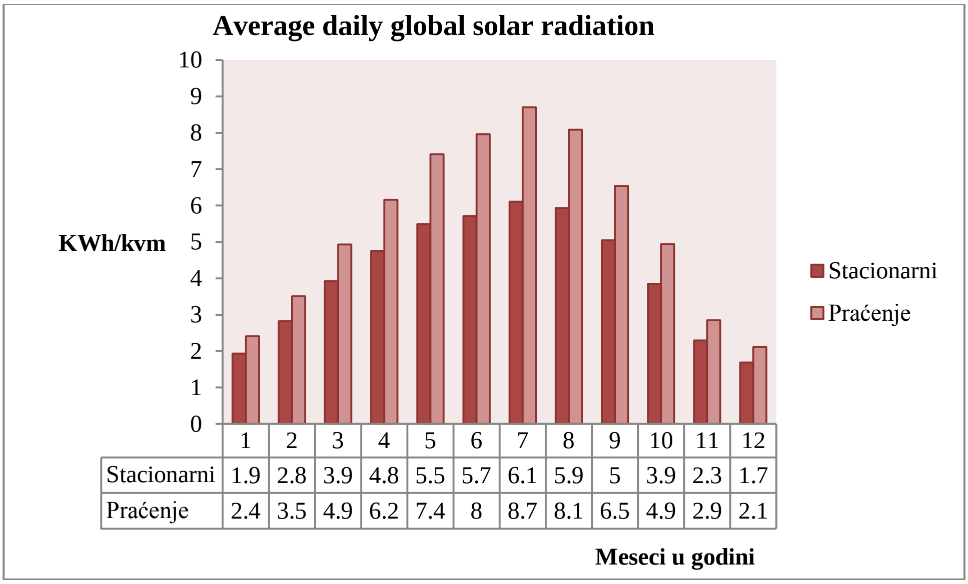
The solution to the above-mentioned problem are the so-called portable, mobile (cell) solar systems for energy production, which can relatively easily and quickly be transferred from place to place with no special ground preparations. Solar photovoltaic devices are made in two variants:

- with a constant angle of inclination;
- with a system for tracking the sun on the horizon.

Its main characteristics that distinguish it from conventional irrigation systems are as follows: It is movable and portable, so it is suitable for use on any ground; It does not require special infrastructure nor ground preparation for the installation; It works independently and isn't connected to the electrical grid; The operating time is several hours with simoultaneous recharging using solar energy; Easy to use and requires no special training or education; Silent in operation, and harmless to the environment; Highly automated with the possibility of remote control; Easy and inexpensive to maintain; The working life of the device is over 20 years; Battery operating life of 1000-5000 charge/discharge cycles can be achieved and depending on the discharge rate the battery is at 20-60% state-of-charge (A. Rodic et all, 2014).

This system is not intended for typhoon irrigation, since it hasn't got sufficient power. It is designed for small and medium-sized family farms, which have up to several hectares of arable land, in one piece or scattered. It has a higher degree of solar energy utilization but it is even up to 30% more expensive to implement. is given in graph 1.

Graph 1. ***Comparative graphical overview of the energy efficiency of these two types of solar power generating systems***



	1	2	3	4	5	6	7	8	9	10	11	12
Stacionarni	1.9	2.8	3.9	4.8	5.5	5.7	6.1	5.9	5	3.9	2.3	1.7
Praćenje	2.4	3.5	4.9	6.2	7.4	8	8.7	8.1	6.5	4.9	2.9	2.1

Source: *Study: „ Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture. " Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.*

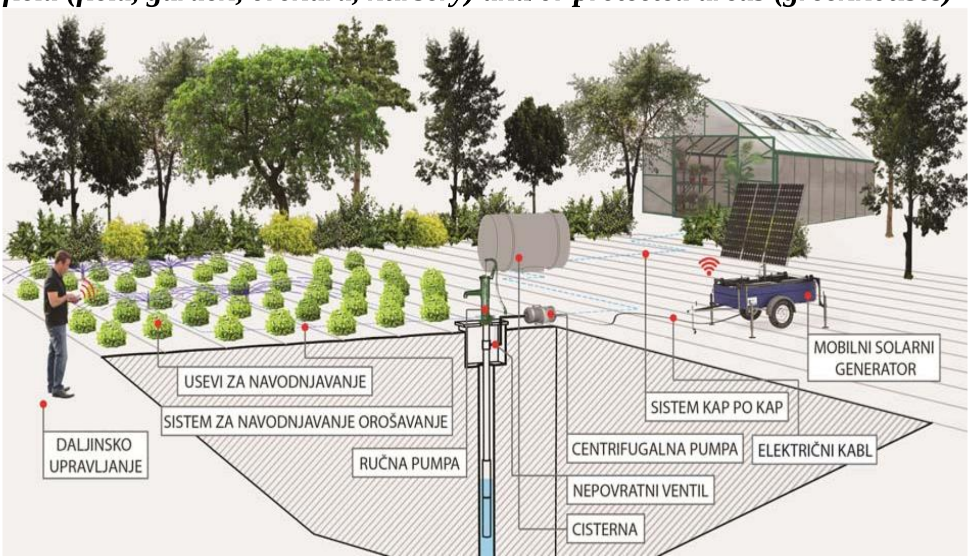
Comparative advantages of using stationary devices with fixed inclination of the panel (blue bars) and mobile solar systems with a solar tracking device (red bars) during the season. The optimum position of the stationary solar system is defined by azimuth angle of α = 1 ° facing south and elevation angle of β = 34 °

Graph 1 presents average monthly and daily global solar radiation in kilowatt-hours per unit area of a photovoltaic panel. It is observed that in the summer months of June, July and August, when irrigation of agricultural land is needed mostly, the level of solar radiation per square metre is the largest. In our region, we get the greatest amount of energy from the sun in July and it is 4 times higher than in December or January. This can be beneficial for irrigation of arable and fruit crops, in a way that photovoltaic systems use solar energy to produce electric power (electricity) required to run the water pumps (single-phase or three-phase).

If we analyze the amount of energy that is obtained by using stationary (with fixed inclination of the panel) and mobile (with a solar tracking device) solar systems, it is evident that mobile devices have the advantage. They are on average 33% more efficient than the corresponding (the same panel sizes) stationary systems. The difference in energy efficiency is greatest in July and amounts to 42% in favour of mobile devices. The smallest difference in the efficiency is in the winter, when the difference between stationary and mobile solar systems is reduced to 25%.

The principle of using solar power generator for irrigation is shown in Figure 1. In order to irrigate in this way it is necessary to have a water source for irrigation (artesian well, classical water well, canal, pond, river, lake); pump facility, 1-4 KW; pipeline and appropriate irrigation system - sprinklers (ie. guns), drip irrigation system, water cannons for irrigation, etc.

Figure 1. ***Scheme of solar power generators used for irrigation in the open field (field, garden, orchard, nursery) and/or protected areas (greenhouses)***



Source: *Study: „ Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture. " Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.*

The main goal of mobile robotized solar power generator study is to determine its technical features and the appropriate economic indicators of the profitability of its application.

In order to analyse techno-economic aspects of mobile solar power generators use in irrigation of crops the test setting was used at 4 different locations, namely:
- In the village of Glogonj-at three locations (Municipality of Pancevo - Pancevo), and
- In the village of Veliko Selo-at one location (municipality of Palilula - Belgrade).

In Glogonj the device has been tested for irrigation in the open field using the sprinkler system (cabbage and cauliflower gardens: location-1 and location-3) and greenhouse drip system (greenhouse tomato production: location-2).

At locations 1 and 3 (open field), the following pumps were used:
- Single-phase vacuum pump 2.200 W;
- Villager petrol engine pump WP 35, 3.700 W;
- SLAP800 diesel engine pump, 7.300W.

At location - 2 (protected area - a greenhouse), a weaker, 1.500 W garden pump was used.

In the village of Veliko Selo the device has been tested for irrigation in the open field using the sprinkler system and 12 mm water cannon (lettuce and leek garden: location-4) and greenhouse sprinkler system (greenhouse lettuce production: location-4).

At location 4 a single-phase vacuum pump of 2.200 W was used.

The research studies have attempted to provide answers to the following questions:

- What is the power consumption of this device?
- How effective is this device in exploitation?
- How many hours of continuous operation can it accomplish?
- How many acres can be irrigated over the course of one day?
- What amount of water can be pumped daily?
- What is the capacity of the unit on a daily, weekly, monthly, seasonal or annual basis?
- What is the lifetime of the device, with different dynamics of use? - What is the term of return on investments through energy savings?
- What are the potential advantages of this device, compared to using conventional petrol or diesel engine pumps?

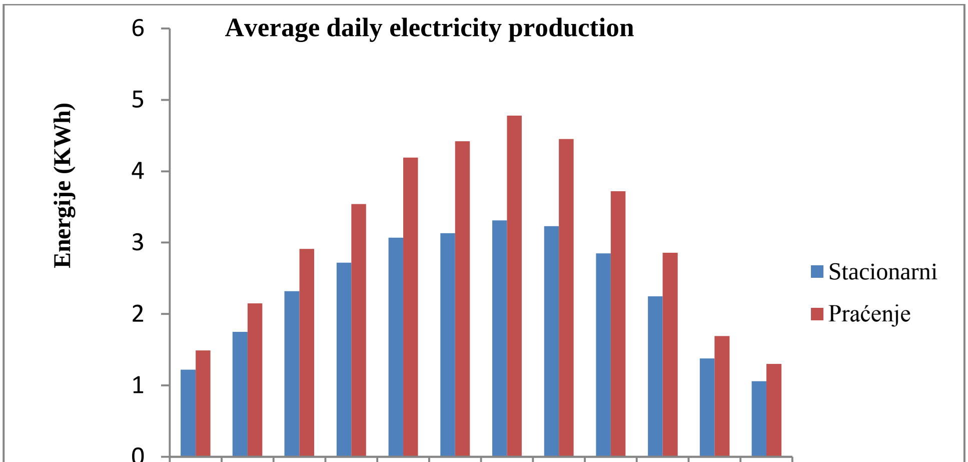
- Answers to the questions above were obtained by putting into operation the system in real conditions of exploitation and the corresponding measurements on the device.

Capacity of the device

The capacity of the mobile solar generator is determined by the battery storage capacity and the amount of daily sunlight. Battery capacity is 480 Ampere-hours and 24 volts. Available energy stored in a battery is calculated by multiplying these two data. Energy derived from photovoltaic panels is added to this stored energy. The amount of solar energy changes throughout the year.

Graph 2 shows the average daily energy production depending on the season. It is the highest in July and the lowest in December. Mobile robotized solar power generator, the tested device, possesses the solar tracking system (STS). It provides maximum utilization of solar energy (red bars on the graph). If the STS deactivated and panels were set up in a fixed position the effects of stored energy would be lower (blue bars).

Graph 2. ***The average daily electricity production depending on the season***



	1	2	3	4	5	6	7	8	9	10	11	12
Stacionarni	1.22	1.75	2.32	2.72	3.07	3.13	3.31	3.23	2.85	2.25	1.38	1.06
Praćenje	1.49	2.15	2.91	3.54	4.19	4.42	4.78	4.45	3.72	2.86	1.69	1.3

Source: *Study: „Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture". Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.*

Electricity generated by photovoltaic panels, along with the energy from batteries can be used to start water pumps of various power.

From experience, batteries should not be discharged to more than 60% state-of-charge, because their lifespan can be shortened due to intensive charging and discharging.

The number of charge and discharge cycles (CD) in the lifespan of a battery is changeable. At 100% depth of discharge, the lifespan is 400 CD cycles, at 60% depth of discharge its lifespan is 1.000 CD cycles, and at 20% depth of discharge its lifespan is 3.600 cycles.

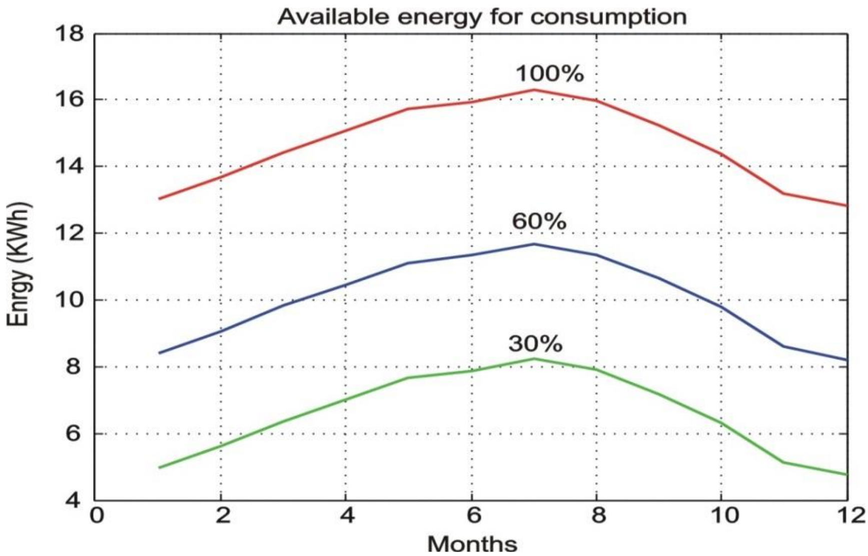
The device will not be damaged if it is completely discharged but the depth of discharge should be taken care of in order to prolong the battery lifespan.

The time needed to fully recharge the system (100%) by using solar energy is about 18 hours of charging, which is achieved in less than two days. At 60% depth of discharge one day is needed in order to fully recharge the system.

The system has an intelligent energy management system which optimizes the work and its use. This is automatic operation mode.

Graph 3 shows the estimated amount of energy that can be used. For example, in July, when solar radiation is the strongest, the device has a supply of 15 kilowatt hours of energy.

Graph 3. ***Available energy supplied by the device at different intensities of battery energy consumption***



Source: *Study: „Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture". Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.*

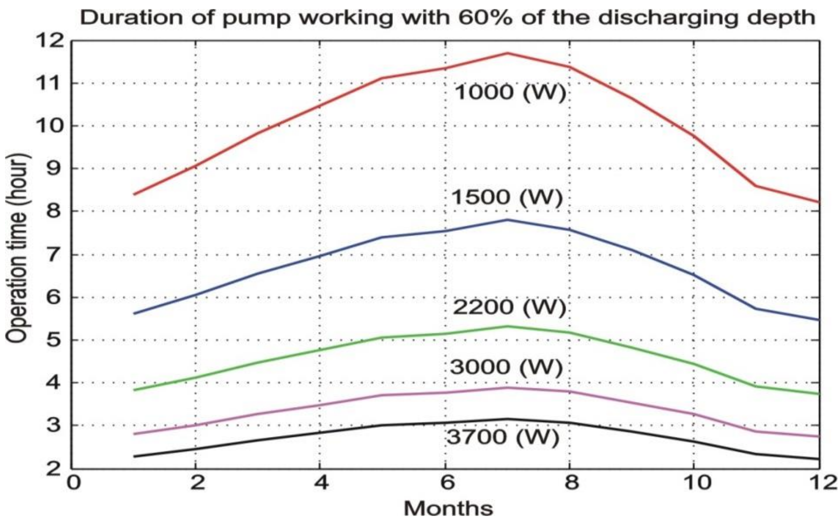
If the intention is not to discharge the batteries beyond 60%, then you can use a little less than 12 kilowatt hours. At moderate consumption of 30% of the battery about 8 kilowatt hours can be used.

The available energy, provided by the mobile solar power generator, can effectively be used to start the water pumps.

If the recommendation not to discharge the battery beyond 60% is adopted, then we can calculate the number of hours of continuous operation.

So, for example, if you use a weaker garden pump, eg. 1.500 watt pump, it can continuously operate for 11,5 hours. Single-phase 2.200 watt pump, that was used in the experiments, can continuously operate for 5,5 hours (*Graph 4*).

Graph 4. Estimated time of continuous operation of the pump at maximum power and at 60% depth of discharge of the battery



Source: Study: „ Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture. " Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.

If we know the height of the suction pump (in Glogonj, it is already at 2-3 metres), the elevation difference the pump has to overcome and the flow through the pump, then we can relatively reliably calculate the amount of water to be brought to a certain agricultural land for irrigation. Approximately 30 litres per square metre is abundant watering, while 10 litres is enough to refresh the crops.

Conclusion

Technical characteristics and capacity of the mobile robotized solar power generator are determined by testing its operation in irrigation of different vegetable crops and in the application of different methods of irrigation: sprinkler irrigation, drip irrigation and 12 mm water cannon irrigation.

Bearing in mind the established capacity of mobile solar power generator, the ideal solution to solar powered irrigation would include the following:

- The capacity of the solar generator is quite sufficient to meet normal customer requirements and remove from use the „dirty“ conventional gasoline and diesel generators for irrigation;
- Single-stage or multistage centrifugal pumps, single-phase or three-phase pumps from 3.000 to 4.000 W with appropriate frequency converter that regulates the impeller speed, and thus the flow and pressure at the outlet, are the most optimal to use. The pump that was used to test the device is slightly weaker than the real user needs demand. However, solar power generator enables 2 weaker pumps to be connected in a line (when the pressure doubles) or in parallel (when the flow doubles). Mobile solar generator allows different connection of the existing power inverters (3 appropriate with 1.600 W), which enables the user to optionally use either single-phase or three-phase pump, depending on their own needs. Three-phase pumps have larger motor power from 3 to 4 KW, while the single-phase pumps have up to 3.000 W;
- Mobile solar generator, being portable, enables farmers to irrigate their crops in several remote locations in the course of one day relatively easily.

In the context of the above, we start from the results shown in the picture above. If we accept, for example, that a single stage centrifugal pump, type PEDROLLO FG2 32/200 AH (or optional F 32/200 AH) http://www.pumpe.rs/katalog2011/katalog_pedrollo_FG_pumpi.pdf, in terms of power and other parameters (p = 4 KW, Q = 100-320 lit / min, p = 4,4 to 5,5 bar), optimally matches the capacity of mobile robotized solar power generator, then the following table should be used for assessing the economic effects of this irrigation system.

Table 2. ***Calculation of energy consumed from the solar generator using the recommended Pedroli water pumps for irrigation of usable agricultural area (intensive irrigation, moderate watering and refreshment of crops)***

Pump type	Hours of operation	Energy (KWh)	Flow (litres)	Extremely soaked-saturated area (ares)	Normally soaked area (ares)	„Refreshed" area (ares)
FG2 32/200 AH	1	3,7	19.200	5.82	9,60	19,20
	2	7,4	38.400	11,64	19,20	38,40
	3	11,1	57.600	17,46	28,80	57,60

Source: *Study: „Techno-economic aspects of renewable energy and mobile robotized solar power generators use in agriculture". Project of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia, 2016.*

33 l/m^2 is spent for intensive watering, 20 l/m^2 for moderate watering and 10 l/m^2 for „refreshment of crops".

The analysis of the results given in Table 2, shows that in moderate irrigation surface area of about 30 ares is irrigated in 3 hours of operation of mobile robotized solar generator. Thereby it consumes 11,1 kilowatt-hours of energy, which at the current electricity price of 9 dinars per kilowatt / hour means that 1 ha of agricultural land can be irrigated at the price of 350 dinars. 15-20 litres of diesel fuel are used to irrigate the same area of 1 ha, which costs about 2.500-3.000 dinars. If we leave out the initial investment for the purchase of solar generator and water pump (not small), irrigation using energy from the solar generator is almost ten times more cost-effective.

The disadvantage of this system relates to the fact that, despite cheap energy, solar irrigation system can daily irrigate up to 50 ares of surface area in 3 hours of operation. After that, the system must be left to „recharge", either by using solar energy, or connecting to the electrical grid (in case of necessity). Thus, the maximum daily irrigation capacity of the tested device is up to half a hectare.

On the other hand, it can be assumed that: - the estimated cost of the device with the basic equipment is around € 7.000,00; - The Ministry of Agriculture and Environmental Protection would subsidize 40% of the purchase price of the device (50% in marginal farming areas); - association of vegetable growers/family household has 3 hectares of production area under vegetables (open field and greenhouse production), whereby two production cycles of a vegetable crop (spring and summer sowing/planting) may be carried out during one calendar year; - the average cost of energy consumed in the process of irrigation of the observed vegetable crops during one production cycle ranged from around 400 EUR (the village of Glogonj), up to about 950 EUR (Veliko Selo).

It can be expected with a high degree of certainty that the period of return on investment in these devices, through energy savings, would be less than 3 years.

References

1. *Akcioni plan za sprovođenje Nacionalne strategije održivog razvoja za period od 2011. do 2017.* „Službeni glasnik Republike Srbije“ broj 62/2011;
2. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy, COM(2011) 21, Brussels, 26.01.2011, European Commission;
3. Cvijanović D., Subić J., Kljajić N., Filipović V. (2012): „*Stanje i mogućnosti razvoja navodnjavanja u Republici Srbiji*“. Nacrt. Nepublikovan materijal. Institut za ekonomiku poljoprivrede, Beograd, april 2012;
4. *EU biodiversity strategy to 2020 (Our life insurance, our natural capital: an EU biodiversity strategy to 2020*, EC, Brussels, 3.5.2011, COM(2011) 244 final);
5. *DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009* on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC;
6. *IPARD program za Srbiju za period 2014-2020.*“, Ministarstvo poljoprivrede i zaštite životne sredine R. Srbije, Službeni glasnik RS, broj 30/2016;
7. Kljajić N., Vuković P., Arsić S. (2011): „*Irrigation in Serbia-development conditions and perspectives*”, pp 100-106, Scientific papers series ,,Management, Economic engineering in Agriculture and Rural Development”, volume 11, issue 1/2011;
8. Kljajić N. (2012): *„Ekonomska efikasnost investicija u različitim uslovima proizvodnje maline“*. Doktorska disertacija. Poljoprivredni fakultet, Univerzitet u Novom Sadu;
9. Kljajić N. (2014): *„Efikasnost investicija u proizvodnji maline“*. Monografija. Institut za ekonomiku poljoprivrede, Beograd;
10. *Nacionalna strategija održivog razvoja*, „Službeni glasnik Republike Srbije“, broj 57/08;
11. *Nacionalna strategija za uključivanje Republike Srbije u mehanizam čistog razvoja Kjoto protokola za sektore upravljanja otpadom,*

poljoprivrede i šumarstva, „Službeni glasnik Republike Srbije“ broj 8/2010;
12. *Nacionalni program zaštite životne sredine*, „Službeni glasnik Republike Srbije“, broj 12/2010;
13. *Nacionalna strategija održivog korišćenja prirodnih resursa i dobara*, "Službeni glasnik Republike Srbije", broj 33/12;
14. *Nacionalni akcioni plan za korišćenje obnovljivih izvora enegrgije* Republike Srbije za period 2013-2015., "Službeni glasnik RS", br. 53/2013;
15. *Nacrt Stategije razvoja energetike Republike Srbije do 2025. godine sa projekcijama do 2030*. Ministarstvo energetike, razvoja i zaštite životne sredine Republike Srbije, 2013;
16. Petković S. (2003): „*Strategija razvoja navodnjavanja u Srbiji*“. Vodoprivreda br. 201 - 202 (2003/1-6);
17. Potkonjak S., Mačkić K. (2010): *„Proizvodno ekonomski efekti navodnjavanja sa posebnim osvrtom na male površine“*, Savremena poljoprivredna tehnika Cont. Agr. Engng. Vol. 36, No.3, str. 256-266;
18. *Popis poljoprivrede 2012, Poljoprivreda u Republici Srbiji, knjiga 1*, Republički zavod za statistiku, Republika Srbija, 2013;
19. *Popis poljoprivrede 2012, Poljoprivreda u Republici Srbiji, knjiga 2,* Republički zavod za statistiku, Republika Srbija, 2013;
20. Rodić A., Vujović M., Despotović Ž. (2016): „*Design of energy sustainable settlements“*, in Proceedings of the 1st Symposium on Sustainable Energy with international participation, pp.135-144, Tara, March, 16th-18th, 2016;
21. Rodić A., Despotović Ž., Jovanović M., Popić S., Stevanović I. (2014): *„Mobile robotic solar generator mobisunproenergy™- application in new energy technologies“*, VIII International Forum for Clean Energy Technologies 2014 energy chapter - Sustainable development of Serbia, Novi Sad, 30th September – 1st October 2014;
22. *Regulation EU No 1305/2013 of the European Parliament and of the Council of 17 December 2013* on support for rural development by the EAFRD;
23. *Roadmap to a Resource Efficient Europe COM(2011) 571 final, Brussels, 20.09.2011*, European Commision;
24. Srđević Z., Srđević B. (2008): *„Dvonamenski sistemi (za navodnjavanje i odvodnjavanje) i asocijacije korisnika u Vojvodini“*. Časopis Vodoprivreda, 0350-0519, 40 (2008) 231-233, str. 69-80;
25. *Strategija poljoprivrede i ruralnog razvoja Republike Srbije za period 2014-2024. godina*, „Službeni glasnik Republike Srbije“ broj 85/2014;

26. *Strategija razvoja energetike Republike Srbije do 2015*. „Službeni glasnik Republike Srbije“ broj 44/05;
27. *Strategija uvođenja čistije proizvodnje u Republici Srbiji*, „Službeni glasnik Republike Srbije“ broj 17/2009;
28. *Strategija naučnog i tehnološkog razvoja Republike Srbije za period 2010-2015.godina: fokus i partnerstvo*, „Službeni glasnik Republike Srbije“ broj 13/2010;
29. *Strategija pametnog, održivog i inkluzivnog rasta „Evropa 2020“ (EUROPE 2020: A strategy for smart, sustainable and inclusive growth, COM (2010) 2020 final, EC);*
30. Studija: „*Tehno-ekonomski aspekti primene obnovljivih izvora energije i mobilnih robotizovanih solarnih elektro-generatora u poljoprivredi*“. Projekat Ministarstva poljoprivrede i zaštite životne sredine Republike Srbije, 2016. god.;
31. *Zakon o strateškoj proceni uticaja na životnu sredinu*, Službeni glasnik Republike Srbije broj 135/04 i 88/10;
32. *Zakon o integrisanom sprečavanju i kontroli zagađivanja životne sredine*, Službeni glasnik Republike Srbije broj 135/04;
33. *Zakon o ratifikaciji Ugovora o osnivanju Energetske zajednice između Evropske zajednice i Republike Albanije, Republike Bugarske, Bosne i Hercegovine, Republike Hrvatske, Bivše jugoslovenske Republike Makedonije, Republike Crne Gore, Rumunije, Republike Srbije i Privremene misije UN na Kosovu“*, „Službeni glasnik Republike Srbije”, broj 62/06;
34. *Zakon o potvrđivanju Kjoto Protokola*, „Službeni glasnik Republike Srbije“ broj 88/07 i broj 38/09;
35. *Zakon o zaštiti prirode*, „Službeni glasnik Republike Srbije“ broj 36/09 i broj 88/10;
36. *Zakon o energetici*, „Službeni glasnik Republike Srbije“, broj 57/11, 80/11-ispravka, 93/12 i 124/12;
37. *Zakon o javno privatnom partnerstvu i koncesijama*, „Službeni glasnik Republike Srbije“ broj 88/11;
38. *Zakon o podsticajima u poljoprivredi i ruralnom razvoju*, „Službeni glasnik Republike Srbije“ broj 10/13;
39. *Zakon o efikasnom korišćenju energije*, „Službeni glasnik Republike Srbije“, broj 25/13;