ENERGY EFICIENCY WITHIN GREEN SOLUTIONS FOR MANAGEMENT OF WATER-ENERGY-FOOD-ENVIRONMENT NEXUS

ENERGETSKA EFIKASNOST U OKVIRU ZELENIH REŠENJA ZA UPRAVLJANJE NEKSUSOM VODA-ENERGIJA-HRANA-ŽIVOTNA SREDINA

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Abstract: *Energy efficiency is one of the most important research subjects in the process of optimal utilization of energy and water for food production, taking care of the environment. This is the requirement of efficient production and use of green renewable enegy within the nexus water-energy-food-environment. Increasing number of inhabitants on the Globe require more energy, water and food. All technologies for energy, water and food production mast respect the criteria of environmental protection. The hydro, solar and wind energy are renewable resources and on the same time they are one of the most sustainable ways of electric energy production. Besides the benefit of clean green energy, the landscape of big solar or wind power plants, or big hydro accumulation and their impact on the environment mast also be the subject for analyses. The aspect of land occupying is a cutting edge research in correlation with the complex goal of using land for food production. This paper presents a green solution for management of the nexus water-energy-food-environment, using renewable resources.*

Key words: *Energy efficiency, green solutions, nexus, water-energy-food-environment, management.*

Apstrakt: *To je jedna od najvažnijih istraživačkih tema u procesu optimalnog korišćenja energije i vode za proizvodnju hrane, vodeći računa o životnoj sredini. Ovo je zapravo zahtev efikasne proizvodnje i korišćenja zelene obnovljive energije u okviru neksusa voda-energija-hrana-okruženje. Sve veći broj stanovnika na Zemlji zahteva više energije, vode i hrane. Sve tehnologije za proizvodnju energije, vode i hrane moraju uvažavati i kriterijume zaštite životne sredine. Hidro, solarna i energija vetra su obnovljivi izvori i istovremeno jedan od najodrživijih načina proizvodnje električne energije. Pored koristi od čiste zelene energije, predmet analize su i pejzaž velikih solarnih ili vetroelektrana, ili velike hidroakumulacije i njihov uticaj na životnu sredinu. Aspekt zauzimanja zemlje je izuzetno zanimljivo istraživanje u korelaciji sa složenim ciljem direktnog korišćenja zemljišta za proizvodnju hrane. Ovaj rad predstavlja zeleno rešenje za upravljanje neksusom voda-energija-hrana-okruženje, uz korišćenje obnovljivih izvora energije.*

Ključne reči: *Energetska efikasnost, zeleno rešenje, neksus, voda-energija-hrana-životna sredina.*

1. INTRODUCTION

More than 70% of fresh water is used for food production [1]. This water often has to be transported from one location to the other, or pumped, which require energy consumption. Water needed for food production can come from the rivers directly, or from artificial accumulations. The water

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behind a dam can be used for energy production, or for irrigation, if the fertile land is upstream from the accumulation. If the fertile land is downstream from the dam and accumulation, water passing through the turbines can be used afterwards for food production if the daily diagram of electriciti production is identical with the diagram of water needs for irrigation and food production. So, all the problems are complex and require to be solved as a green optimal solution, taking care of the environment and climate change on the same time. This subject also requires interdisciplinary research and holistic approach.

Today, in the world, numerous wind power plants and solar power plants are installed above fertile arable land. There is not enough space on the globe for all the activities necessary in the process of providing the basic needs of humanity in terms of the needs for water, energy, food and a clean environment.

Optimal management of resources is and will always be a complex and demanding problem for scientists, engineers, managers and decision makers. The first level of optimization can be related to the question of how much area of fertile land should be allocated for installations of renewable energy sources, and how much for agriculture, i.e. food production.

The problem is complicated when you learn that it is possible to install a wind power plant and/or a solar power plant on the same agricultural land.

When the research topic is hydropower, the problem is defined as either/or. In that case, the land surface can be used either for the construction of a dam and reservoir, or for planting agricultural crops.

Electricity is needed by mankind, but also for the improvement of agricultural production, which makes the problem two-layered, complex and interdisciplinary.

2. MATERIALS AND METHODS

The methodology applied within this research is related to the research on three the most implemented renewable resources (solar, wind and hydro energy) in correlation with the fertile land use, within the nexus water-energy-food-environment (WEFE) nexus. Methodology encompasses:

- Collection and review of all existing engineering designs, documentation and published scientific articles in the field of water-energy-food-environment nexus
- Desk research,
- Expert’s analyses,
- Conducted questionnaire method,
- Survey method,
- Interview method (with key authorities and affected communities) and
- Site inspection method.

Solar and hydro energy in correlation with fertile agriculture land use were researched by first three above mentioned methods. Last four methods were applied for wind energy interaction in WEFE nexus.

Research into the acceptance of developing more efficient application of solar, wind and hydro energy in the context of WEFE nexus synergy was done. The methodological holistic approach also includes methods of induction and deduction, analysis and synthesis, as well as the analogy method. Examples of positive world practice are also given. The results were completed and mixed with the research method - interview, where public and expert hearings were examined.

Experimental research was carried out in June and July 2023 in southern Banat in Serbia and in Belgrade. In order to cover as high a population as possible and to generate quantitative data, the questionnaire as a research instrument was conducted on a representative sample of 105 respondents. Respondents' answers were processed using statistical methods. The data collected were processed using Microsoft Excel and SPSS for Windows 13.0 software packages. Additionally, a mixed method was applied and the research completed with an interview. In order to quantify the indication (validated) by qualitative information, the author interviewed 10 sample respondents. An interview was conducted with the same questions, but the answers were explained in detail by the respondents. These 10 respondents were mainly experts in the domain, or persons in executive positions.

The site inspection of a wind power plant Čibuk 1 is organized. Power plant Čibuk 1 is on fertile agriculture land. Questionnaire is presented in the Table no 1. Survey is organized within 105 inhabitants. Interview with key authorities in Belgrade, in Mramorak and in Kovin was conducted, as well as the interview with affected communities and non government organization (NGO). The results are presented in the next chapter.

Table 1. Questionnaire on implementation of solar or wind energy for electricity production in Serbia with WEFE nexus

Full name	
Occupation, title, education	
Position in the employment	
Job description	
1. Do you know any solar plant or installed photovoltaic panels, or wind farm in Serbia?	➢ yes Be specific. Add technical detail, if possible. ➢ no
2. Does legislation in the domain of RE energy application in Serbia follow EU legislation?	➢ yes ➢ no
3. Why have not more people invested in solar, wind or other mode of RE in Serbia so far?	➢ Shortage of money ➢ Insufficient incentive tariffs ➢ Unstable incentive tariffs ➢ General market instability ➢ Open answer
4. Would you, if you had the necessary funds, invest in solar, wind or other RE power plants in Serbia?	➢ yes (Where?) ➢ no
5. Would you invest in another country? Which ones?	➢ yes (Where?) ➢ no
6. What is blocking greater application? What are the obstacles for faster development and greater use of RE energy in Serbia?	Open answer If necessary, continue on the back of the sheet.
7. Do you think the construction of the solar or wind power plant threatens the agricultural land below?	➢ yes ➢ no
8. Do You know what is WEFE nexus	➢ yes ➢ no
9. Would you rather use water to produce energy, or to produce food?	➢ water for energy production ➢ water for food production
10. Additional comments	

This questionnaire refers to researching whether there is higher interest in Serbia for investing in solar, wind or hydro RE, as well as what is the level of knowledge about their interaction in the context of WEFE nexus.

3. RESULTS AND DISCUSION

This chapter encompasses results of solar, wind and hydro renewable energy implementation and their interaction with fertile agricultural land usage within WEFE nexus.

3.1. SOLAR ENERGY

Global environmental concerns and the escalating demand for energy, coupled with steady progress in renewable energy technologies, are opening up new opportunities for utilization of renewable energy resources. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The power from sun intercepted by the earth is about 1.8 × 1011 MW, which is many times larger than the present rate of all the energy consumption. Photovoltaic technology is one of the finest ways to harness the solar power. This paper reviews the solar energy potential in the world and in Serbia, as well as its environmental aspect coupled with a variety of its applications and landscape management, related to the big solar power plants development in correlation with the land occupation [2].

Two-thirds of the pollution on the globe comes from the production of electricity. The production of healthy food requires a healthy environment, unpolluted agricultural land, clean air, and clean surface and underground water.

Solar photovoltaic have great promise for a low-carbon future but remain expensive relative to other technologies. The 21st century will be characterized by a huge energetic demand: world population is steadily increasing (65 billion in 2005, an estimated 75 billion in 2020 and 9 billion in 2050) [3], and there are hundreds of millions of people in emerging countries (China and India in particular) which are rapidly reaching the welfare of Western countries. The world's total energy consumption for 2030 was estimated at about 181014 KWh [4], of which about 1/10 was used as electricity. Fossil fuels, in particular coal, oil and gas, contributed with about 80% and 65% to the generation of world total energy and electricity, respectively. It is obvious that these resources on Earth are finite, and it is also clear that their use is causing great social and economical problems for the world, in relation to geopolitical instabilities in controlling energy sources and global climate: greenhouse gases, which are thought to be the main reason for global warming and climate change, are mostly produced by burning fossil fuels.

In order to preserve human civilization and enable the social and economic development of billions of people in the third world, the answer to the "energy problem", the problem of food and water shortages must be found in the coming decades and should be considered the main topic of political, scientific and engineering discussions in all countries.

Nevertheless, electricity is the basis of all civilized countries and industrialization, and its access is a fundamental step towards achieving people welfare, including the goal of sufficient food and enough water. As reported in[5], 65% of the World's total electricity consumption is obtained from fossil fuels; about 20% comes from nuclear power plants and the rest is produced by means of renewable sources, such as hydropower [6], biomasses, PV, eolic and geothermal sources: these sources are seen as the most promising ways of granting electricity to the whole world, and can help to reach a self-sustaining energy system.

Currently, solar power plants, is still expensive (although prices per kWh have rapidly decreased fast in the past years), comparing with wind power plant, has a longer money payback rate (8–10 years even with a feed-in tariff) and poses important technological challenges, but can be directly used by the final client even in remote locations, does not necessarily require a grid connection (or work in a "net metering' buyback, if a grid is present), is noiseless, maintenance free, reliable for more than 20 years and can be integrated in consumer electronics for low-power applications [7].

Moreover, solar irradiation in third world countries is extremely high and is seen as the most obvious way to electrify isolated communities. Since the total amount of solar energy reaching the Earth's surface has been calculated at more than 10 000 times the world's total energy consumption, it is obvious that this source, if correctly and efficiently used, can supply the substantial part or even all of our future energetic needs. Nevertheless, markets and clients are still dubious regarding the adoption of eolic energy and PV modules, as their price is perceived as being too high compared to fossil fuels. But it has to be stressed that current energy rates do not include externalities, i.e. 'The major impact and costs originating from the production and consumption of energy related activities such as fuel cycles' [8].

These costs arise when an activity with a specified price has an impact on another activity, and imposes on the latter an additional cost that was not accounted for in the former price. Greenhouse gases, car exhaust and chemical waste are typical examples of externalities of fossil fuel use [9], because their social costs (not only monetary, but also related to global warming, cancer, illness, etc) are not considered in the market price. If the price of electricity generated by fossil fuels included externality costs, renewable sources could become more competitive. The adoption of renewable for power generation is slow because of the existence of several development and market penetration barriers, most of which are not scientifically related [10]. Some of these impediments are:

- Economic (lack of competitiveness and internalization of external costs of energy use),
- Institutional (lack of co-ordination in governments and institutions, long-term planning policy requirements),
- Network (monopoly of generation, transmission and distribution of electricity),
- Social (lack of interest in future energy development and sustainability, doubts about new technologies),
- Financial (lack of funding for research or pilot-installation).

Only a long-term policy can aid a niche market in developing, expanding and gaining the political and economical power needed to bring a new technology out of the niche and distribute it to everyone. This road was followed by Germany, now the second world leader in the installation of PV solar panels, also thanks to the feed-in tariff introduced in 2000. There are several reports and market studies that analyze the trend in PV installation all over the world [11].

During the past 4 years Japan, Germany and USA have emerged as leaders in the total kWp installed, sharing together about 90% of the world market. Globally, in 2003 about 753 MWp PV systems were installed, and the 1 GWp barriers was exceeded in 2004. The trend in the PV market has shown an annual increase of about 30% from 2000 until now, making PV one of the fastest growing industries.

Consequently, PV is attracting more and more actors, even if the 10 biggest companies alone share about 90% of the global market; according to some studies, a demand increase is expected thanks also to the introduction of feed-in tariff in more and more countries (e.g. Italy and Spain) and the fulfillment requirements of the Kyoto Protocol. In order to reduce CO_2 emission, the European Council has stated that in 2030 up to 4% of the World's electricity should be generated by PV.

Estimates suggest that world energy consumption in 2050 will be about 25 Gtoe, or 271014 kWh and, if the world wants to avoid social, economic and environmental problems, the largest part of this energy should be produced by renewable. Moreover, the development of emerging countries as well as their energy policy should not follow the development trend of today's civilized countries, particularly with regards to electricity generation.

Concerning PV (and renewable in general), a very long policy planning period is most definitely needed, in order to support the creation of market demand, the assignment of public funding (with feed-in tariffs), and in order to continue a heavy research and development process [12].

3.2. SOLAR POWER PLANTS AND LANDSCAPE MANAGEMENT

Large-scale solar power plants are being developed at a rapid rate, and are setting up to use thousands or millions of acres of land globally. The environmental issues related to the installation and operation phases of such facilities have not, so far, been addressed comprehensively in the literature [13]. It is identified 32 impacts from these phases, under the themes of land use intensity, human health and well-being, plant and animal life, geohydrological resources, and climate change. Appraisals assume that electricity generated by new solar power facilities will displace electricity from traditional generation technologies, which are not clean. Altogether in the scientific literature [14] it is find 22 of the considered 32 impacts to be beneficial. Of the remaining 10 impacts, 4 are neutral, and 6 require further research before they can be appraised.

None of the impacts are negative relative to traditional power generation. In quantitative terms, large-scale solar power plants occupy the same or less land per kWh than coal power plant life cycles. Removal of forests to make space for solar power causes CO_2 emissions as high as 36 g CO_2 kWh^{-1}, which is a significant contribution to the life cycle CO_2 emissions of solar power, but is still low compared to CO_2 emissions from coal-based electricity that are about 1100 g CO_2kWh^{-1} [15].

Solar energy for the production of electric energy is one source of renewable energy which is experiencing most development in recent years. In countries with high solar radiation indices, as is the case of Spain, expectations of installation of large solar power plants are increasing.

Most solar power plants are located in rural environments [16], where the landscape has remained practically unaltered ever since extensive agriculture was introduced. Because of this, one of the most significant environmental impacts of this type of installation is the visual impact derived from the alteration of the landscape. In the literature [17] an indicator is proposed for the quantification of the objective aesthetic impact, based on four criteria: visibility, color, fractality and concurrence between fixed and mobile panels.

The relative importance of each variable and the corresponding value functions are calculated using expert contribution. A study of the subjective aesthetic impact is carried out using the semantic differential method [18], to obtain the perception of a sample of individuals of the initial landscapes and of the landscapes altered through the installation of a solar power plant. The combined use of objective indicator and subjective study, faithfully explains user preferences corresponding to the combined comparisons. The tools proposed for the evaluation of the aesthetic impact of solar power plants can be useful for the selection of optimal plant location and most adequate use of panel technology, to minimize aesthetic impact [19].

Renewable energy has developed spectacularly in Spain since the European Union started a process of energy policy reform. A review of Spanish State legislation on renewable energies confirms that the success in installing renewable energy is attributable to public aid. Andalusia is one of the autonomous communities, which has simultaneously developed the legal framework and very successfully implemented the introduction of renewable power. When implementing the central government’s policy, the Andalusia regional government prioritized increases in surface cover by solar plants (thermal and photovoltaic energy) and in the number of companies involved [20]. However, this development of renewable energies took place without any proper integration into regional spatial and landscape planning. That is why it is necessary to investigate renewable power implementation through regulatory measures put in place over the last decade to develop renewable energy systems and the way they can be managed alongside planning issues, especially in correlation with the area of occupied fertile land, which can be used for food production [21].

3.3. SOLAR POWER PLANTS AND INTERACTION WITH FERTILE AGRICULTURAL LAND

There are many solar power plants in the world occupying hectares of fertile agriculture land. For example solar power plant Shams 1 in the United Arab Emirates. The power plant was built three years. It reaches the electrical power of 100 MW by consisting of 258,000 mirrors arranged at 768 cilindro-directional parabolic collector. Occupying an area of about 285 football fields, this power plant provides electricity for 20,000 Emirates households and saving the emission of around 175,000 t of CO_2, which is equivalent to planting 1.5 million trees, or removing 150,000 cars from the roads of Abu Dhabi. In addition, the power plant Shams 1 has a modern system of air cooling, which will significantly reduce water consumption, which is the most valuable resource in the desert regions of the Middle East. Possible improvement in the direction of WEFE nexus would be if the energy prodused by this solar power plant would be used for pumping water from underground layers and irrigating the desert with the goal of food production.

One other large-scale solar power plant was solar thermal power plants with a central receiver, constructed in Ivanpah, in the Mojave Desert in California. The plant occupies an area of 1,400 hectares. It was built three years ago and put into operation in early 2014. Total investment costs for this solar power plant Ivanpah amounted to 2.2 billion USD. This solar plant can annually supply with electricity about 140,000 California households.

Positive practice to be followed is the interactive green solution of solar energy implementation with agriculture development in synergy, as it is presented on the Figure no 1.

Figure 1: Agrivoltaics - solar renewable energy in synergy with agriculture as WEFE nexus

Renewable energy produced in solar power plant with the facilities developed on fertile agricultural land, could be used for households in the nearest villages. This energy could also be used on the spot for irrigation purposes for supplying different agriculture equipment with the electricity, as well as for pumping the water for irrigation from the underground or from certain surface water courses.

3.4. WIND ENERGY IN SYNERGY WITH FERTILE AGRICULTURAL LAND

Wind energy is clean, green, renewable and sustainable energy. Numerous wind farms are being built around the world in suitable locations. One of the most negative possible impacts on the environment is the impact on migratory birds. Therefore, along with technical projects, environmental impact studies must also be developed. There is also the question of land occupation and the use of fertile agricultural land under the wind turbines. Figure 2 present possible synergy between wind power energy production and agriculture fertile land use.

Figure 2: Wind power plant and positive interaction with agriculture

The latest research has shown that under wind turbines it is possible not only to develop agriculture, but even that wind turbines can have a positive effect on agricultural yields. So, wind power plants may do more than improve farm income. When sited in agricultural fields, turbines' churning of air may help crops to grow.

Renewable energy produced in wind power plants with the facilities developed on fertile agricultural land, also could be used for households in the nearest villages, as well as for irrigation purposes for supplying different agriculture equipment with the electricity, or for pumping the water for irrigation from the underground or from nearest surface water channel.

More and more big wind farms are being built in Serbia. One of them is "Čibuk 1". Čibuk 1 wind farm is the largest commercial energy project in the field of wind energy in Serbia and the Western Balkans, with 158MW installed power. This wind power plant has 57 turbines. The pillars of the wind turbines are arranged so that they are at a distance of four pillar heights in width and seven column heights in depth in the direction of the wind. In this way, wind turbulence is avoided and the highest energy efficiency is achieved.

Čibuk 1 wind power plant can prevent more than 370,000 tons of carbon dioxide emissions per year. The investment worth about 300 million Euros was supported by the International Finance Corporation (IFC), a member of the World Bank group, and the European Bank for Reconstruction and Development (EBRD). The conducted questionnaire showed that the investor has followed all the technical, regulatory and environmental requirements.

Within this research, a questionnaire was conducted on a representative sample of 105 respondents, with the aim of exploring the interest of extending production of electricity from wind power in Serbia. 52 subjects from the subgroup *a,* are experts in the domain of wind energy production. In 98% of the cases they are doctors of science. Subgroup *b,* consisting of 53 respondents of different educational levels, age and gender, were randomly selected. The average age of subjects from the subgroup *a,* was on average 59 years, and from subgroup *b,* 37 years. The representation of women in subgroup *a,* is 3%, and in subgroup *b,* the target was 50%. The level of education in subgroup *b* was: 37% high school, 33% secondary school and 30% basic education.

Respondents from subgroup *a,* have of course shown as expected, a very high level of knowledge about wind power plants and all related technical details. It is interesting that subjects from subgroup *b,* also showed a relatively high level of knowledge about wind energy. 68% of subjects from subgroup *b,* had knowledge about the installed wind power plants, which means that in Serbia have been activities on informing and raising awareness about the importance of using wind energy. 93% of respondents from subgroup *a,* responded that Serbian legislation generally follows EU regulations within the domain. The questionnaire supplemented with interview method showed that all key authorities were involved in the decision-making process correctly and adequately, as well as the affected community and NGO.

3.5. HYDRO ENERGY, WATER AND AGRICULTURE LAND USE WITHIN WEFE NEXUS

Energy efficiency is not only related to the saving of the energy in the households and buildings. It is also one of the most important subjects in the process of optimal utilization of water and energy for food production, taking care of the environment. This is actually the requirement of efficient production and use of green renewable energy within the WEFE nexus.

Model of WEFE nexus will be presented through case study of Drina River. The countries that share the Drina river basin are Bosnia and Herzegovina, Montenegro and Serbia. That is why joint development plans must be made, especially development plans related to the planning of a large number of new hydropower plants, because they can significantly affect the environment, but also affect other sectors, especially energy, agriculture and water management. Likewise, the commitments undertaken by all countries in relation to environmental protection, climate change mitigation and GHG reduction are changing economic perspectives. All these influencing factors should be taken into account when discussing plans through the prism of the WEFE nexus, see Figure 3.

Figure 3: Water for energy and food in clean environment - WEFE nexus

An integral assessment of resources has shown that the coordination of the operation of power plants along the Drina River and its tributaries can significantly increase electricity production downstream, as well as agricultural production. The power system model was developed for three states in the river basin as part of a systematic cross-sectoral connectivity project, a nexus covering water, energy, food and environment.

If such complex approaches to water management had been implemented in a timely manner, such level of flooding would not have occurred, nor would there have been damage to the fertile agricultural land of Mačva and Semberija. Dams built upstream in the basin of each river contribute to increasing the degree of flood protection, because in the pre-discharge mode, the flood wave can be significantly reduced and mitigated.

4. CONCLUSION

The goal of this interdisciplinary research was to raise the level of knowledge about the WEFE nexus and thereby contribute to the improvement of the integrated management of natural resources and greater energy efficiency during the implementation of RE.

The WEFE nexus concept helps identify benefits and synergies in natural resource management, in order to achieve:

- Security of water, energy and food
- Preservation of the environment and its functions
- Increased resistance to the climate change and
- Reduced GHG emissions

This research also supports the implementation of the 2030 Agenda, accelerates the transition to a green economy, and also strengthens the dimension of sustainable development and the strategy of energy, water and food for all, while preserving the environment.

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