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Improving the vegetable growing by the use of new technologies

Abstract: *Vegetable growing represents the significant segment of the overall agricultural activity, as the vegetables are essential component of the human nutrition. In line to population growth trends, climate change and ecological issues, rapid urbanization and development of other economy's activities to the detriment of agriculture, frequent energy shocks, etc., there are constant confrontation of increase in demand for vegetable crops and available supply at global or national markets. In this circumstances, the stable and high yields in vegetable growing are not conceivable without the use of modern technologies, i.e. without the application of contemporary science. The primary goal of the paper is to consider some technical features and economic effects derived from the investment in appliance of few hi-tech solutions mainly based on the use of renewables in vegetable growing, or even in their processing (such are solar mobile robotized electro-generator, "Smart farm" concept, "Agrokapilaris" irrigation system, or solar dryer). Economic effects are reconsidered in accordance the use of general static and dynamic indicators for the assessment of investment economic efficiency. Gained results demonstrate that the investment in observed production alternatives are economically highly recommended, and above all ecologically and socially very welcomed.*

Keywords: vegetable growing, new technologies, renewables, science, Serbia.

Introduction

Vegetable production has profiled its importance in line to human necessity for involving the vegetables in daily nutrition (Hazra, Chattopadhyay and Karmakar, 2011). Besides nutritional, vegetable usually carries strong medicinal benefits (Jena et al., 2018), as they represent large reservoir of various vitamins, minerals, valuable proteins, fiber and carbohydrates, antioxidants, and many other phyto-chemical compounds (Rodriguez-Casado, 2016; Zapucioiu, Sterie and Dumitru, 2023). Vegetables are part of complete, healthy and well-balanced meals in human diet (Liu, 2013), while their consumption affects the good psychophysical state of organism (Finch, Cummings and Tomiyama, 2019). Besides, they prevent, reduce or even eliminate some human disease and health disorders, such are intestinal, cardiovascular, blood and skin, cancer, endocrine and other disorders (Guan et al., 2021; Rao and Rao, 2007; Oguntibeju, Truter and Esterhuyse, 2013). In general, vegetable could be consumed as fresh (raw) or processed, mostly as frozen, pasteurized and canned or dried (Rickman, Bruhn and Barrett, 2007), while it could be eaten as single or as a part of several salads and dishes (Achikanu et al., 2013). Besides in human nutrition, they are irreplaceable element in many industries, such are food and feed industry, textile industry and light chemistry, medicine and pharmacy, cosmetology, etc. (Morin-Crini et al., 2019).

The main goal of this research is to present economic effectiveness of investment in few technological innovations (use of renewable energy sources and subsurface irrigation system) implemented in vegetables production. Innovations are developed in Serbian academic community and locally tested, while they are ready for the further use in vegetable growing and processing on a regional or even global level.

Literature review

Globally, in line to population growth and more intensive popularization of healthy nutrition, there are coming to constant increase in demand for vegetables at worldwide markets (Mason D'Croz et al., 2019). The rise in demand represents the actual issue for vegetable producers, while shaping their strivings to adapt, solve or adjust many technological, organizational, production, environmental, logistic, marketing and other problems and requests (Lumpkin, Weinberger and Moore, 2005; Rolle, 2006; Villalobos et al., 2019).

In 2021, worldwide vegetable production counted to 1,156 million metric tons of fresh agro-products, while over the 78 % of production was settled in Asia. As the top producers are marked China (52 % of global production), India, USA, and Turkey, while the most produced fresh crops were tomatoes (over the 16 % of overall vegetable production), onion, cucumbers, and cabbage (Shahbandeh, 2023). At worldwide level the top vegetable suppliers are set within the "global vegetable belt", including Eastern and Central Asia, Mediterranean countries, or mainly the countries from Southern Europe and North Africa (Dong et al., 2022).

Currently, vegetable is producing in almost all available crop production systems (conventional, integrated or organic production, hydroponic production, etc.), in protected areas or in open field (Ozkan, Kurklu and Akcaoz, 2004; Sabir and Singh, 2013; Sharma et al., 2018). Related to generally short vegetation period and high requirement in water, it usually considers irrigation (Locascio, 2005; Shock et al., 2007). Vegetable production is highly intensive and very profitable sector of agro-food production (Joshi, Joshi and Birthal, 2006; Mariyono, 2018). Pronounced production seasonality, expressed perishability of fresh products and adjustment to demand at distant markets, usually requires organization and maintaining of adequate logistic (storing, packaging and transportation)

(Onwude et al., 2020; Surucu-Balci and Tuna, 2021). Production is the most often organized at the small farms (Dinham, 2003). Realization of fresh vegetables intended for direct consumption is usually throughout the short supply chains, i.e. retail and green markets, while the large quantities are directed to processing industry too (Vojkovska et al., 2017).

Despite the health benefits and authorized recommendations (per capita consumption has to reach at least 240 g/day) (Kalmpourtzidou, Eilander and Talsma, 2020), in average the consumption of vegetable at global level is under the proposed quantity, around 185 g/day, and differing from 55 g/day in Central America to almost 350 g/day in East Asia. Pronounced differences in vegetable consumption in certain countries largely depends to general income level, culture and tradition in nutrition, etc. (Kalmpourtzidou, Eilander and Talsma, 2020).

Contrary to demand, on offer side there are permanent expectations turned to increase in yields and quality of produced vegetables. Faced to effects of global climate changes, increasingly sharp requests of environmental protection, stronger pressure of plant diseases and pests, energy, economy and logistics shocks, certain social and health tendencies, etc. (Ayyogari, Sidhya and Pandit, 2014; Barnwal and Sharma, 2005; Richards and Rickard, 2020; Robačer et al., 2016), producers are forced to constantly flirt with core science, i.e. wide range of new technologies and innovations, in order to reach overall sustainability of preformed production (Dias and Ortiz, 2021; König et al., 2018; Razin, Taktarova and Semenov, 2018). It has to be noted that in current times followed by almost constant economy and energy crises exposed in certain level, facing with climate change consequences and rise in environmental issues, there are a question should we or not generally skip to the use of renewable energy sources (RES) in agriculture, specifically plant production, instead the fossil fuels. Transition to RES exploitation will surely affects the level of emitted GHGs, enabling the better maintaining of available natural ecosystems and environmentally much comfortable agricultural production (Stoian, 2021). Besides, usually implementation of new technologies and innovations in agriculture is the subject of national subsiding (Feder and Umali, 1993; Wu et al., 2022).

Methodology

Methodology framework implies the use of descriptive method, for describing the available technological solutions that could be used in vegetable growing, as well as desktop research for considering current situation and issues in observed topics, and static and dynamic methods commonly used in investment analysis. Used methods and derived results have, both, to inform and encourage the vegetable growers to accept presented or similar innovations as the one of instruments for reaching the overall sustainability of their farm business.

Presented technological alternatives, mainly linked to the use of renewables in plant (vegetable) production, have been developed, tested and implemented through few pilot projects in last several years by the scientific institutions from Serbia, national and regional leader in the field of energetics, robotics and IT technologies Institute "Mihajlo Pupin" (IMP) and Institute of Agricultural Economics (IAE) from Belgrade, regionally recognized scientific institution from the field of agro-economy and rural development. So, presented data and results mainly derive from techno-economic analyzes that were followed implemented projects.

Results and discussions

Research results derives from the primary goal of research. There will be presented certain technical characteristics and assessment of economic effects gained in investing into the development and implementation, or practical utilization of few modern technological solutions tested in vegetable growing and processing, that implies the use of RES. Presented technical solutions are: Solar mobile robotized electro-generator, "Smart farm" concept, "Agrokapilaris" irrigation system, and solar dryer.

Solar mobile robotized electro-generator

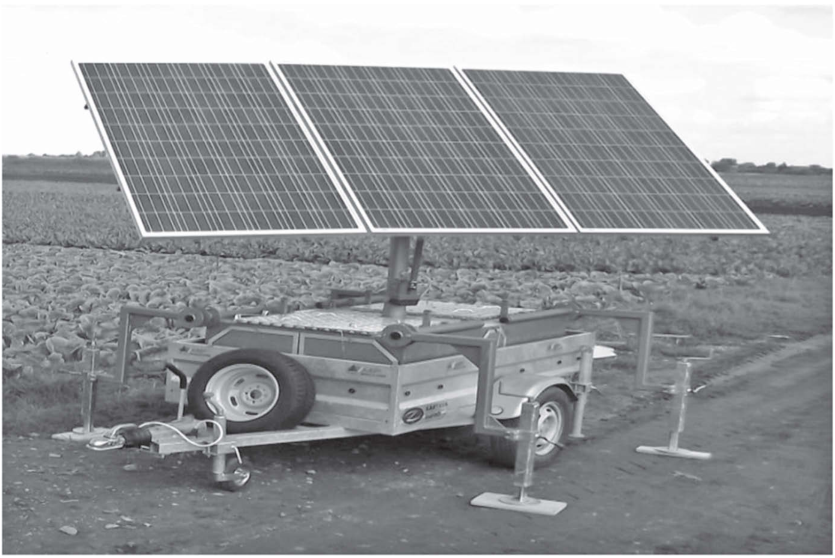
RES as a part of power supplying systems in agriculture could be used for performing many activities, such are irrigation, animal feeding, internal transportation, fish ponds aeration, greenhouses or stables heating, ventilation and lighting, drying, etc. (Ali, Dash and Pradhan, 2012; Chel and Kaushik, 2011). Among available RES, large attainability and relatively cheap access to the solar energy worldwide, found this energy source as one of the most used RES in many sectors of economy, including agriculture (Chikaire et al., 2010; Mekhilef, Saidur and Safari, 2011).

In line to global strivings to include science more deeply into the solving the actual issues related to climate change, GHGs emission, pollution, or sustainability of agriculture, imperative is development and implementation of new technologies. RES and clean technologies could consider the adequate solution as they support zero emission.

Previously, by the IMP Belgrade, developed mobile robotized solar electro-generator was tested in practice during the 2015, by the IMP and IAE Belgrade.

Testing encompasses power supplying of the sprinkler and drip irrigation systems used in vegetable growing, in order to assess the ecologic and economic benefits of such an innovation. Testing location were in villages near Belgrade and Pancevo, traditionally oriented to vegetable production in open field and protected area. The developed solar electro-generator represents highly efficient device strongly adjusted to ecological principles. Related to its capacity and characteristics, its mainly developed for the use at small to medium farms (Picture 1).

This is stand-alone device that doesn't require any energy infrastructure. Although it can be used in many economic activities its mainly constructed to serve in agricultural production. It provides energy supplying in noiseless and environmentally clean regime of work. It could be paired with soil and atmosphere sensors, and digital weather station towards the evaluating the available production conditions due to adequate and prompt producers responds. General benefits of its use are high mobility, small dimensions, independent, quite automatized and remote work, autonomy in work supported by permanent recharging of installed battery banks, users friendly use, cheap maintaining, long-lasting exploitation period for over 20 years (or up to 5,000 cycles of battery charging), possibility for sun tracking, many possibilities for different utilizations, etc.



Picture 1. Solar mobile robotized electro-generator

Source: IMP and IAE internal documentation.

Basic model assumes three-phase generator with maximal power of 5.5 KW and usual 3–8 hours working autonomy, while it could be upgraded to for 50 % more powerful model with stronger batteries. Besides, it could be hybridized into the electric aggregate that joins wind turbine and solar panels (Despotović et al., 2017; Jeločnik and Subić, 2022; Subić and Jeločnik, 2016, 2023).

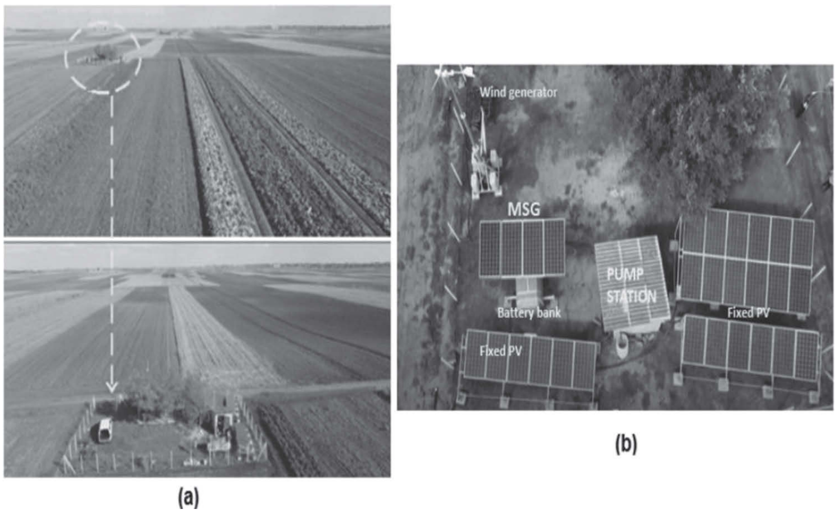
Table 1. Resume of the investment in solar mobile robotized electro-generator used in vegetable irrigation (in EUR)

No.	Element	
1.	Estimated value of investment (EUR)	
1.1.	Total investment	7,700.00
1.2.	Investment in fixed assets	7,000.00
1.3.	Investment in PWC	700.00
2.	Financing sources	
2.1.	Sources – total	7,000.00
2.2.	Own resources	7,000.00
2.3.	Other sources (subsidies)	–
2.4.	Interest or discount rate (%)	5 %
3.	Object of investment	
3.1.	Investment	Investment into purchase of mobile robotized solar electro-generator
3.2.	Starting date of establishment	During 2015
3.3.	End date of establishment	During 2015
3.4.	Project economic life cycle (in line to usual credit line)	5 years
4.	Expected economic effects	
4.1.	*Static assessment*	
4.1.1.	Total Output-Total Input Ratio (%)	1.08
4.1.2.	Net Profit Margin (%)	6.37
4.1.3.	Accounting Rate of Return (%)	27.05
4.1.4.	Payback period	2 years and 7.88 months
4.2.	*Dynamic assessment*	
4.2.1.	Net present value	7,680.20
4.2.2.	Internal rate of return	31.99 %
4.2.3.	Payback period	2 years and 11.08 months
4.3.	*Break-even point analysis*	
4.3.1.	Break-even point (%)	6.80
4.3.2.	Rate of safety (%)	93.20

Described electro-generator could be economically, socially and environmentally desirable energy supplying option, especially at small and remote farms. Main elements derived from the investment analysis linked to purchase and use of mentioned power plant are presented in next table (Table 1). According to obtained indicators, the purchase and the use of the solar mobile robotized electro-generator sounds as reasonable business decision for the potential investor.

"Smart farm" concept implementation

In confronting the rise in awareness to negative natural trends and strivings to more comfortable performing of agricultural activities that will support farms sustainability, comes to establishment of smart farming concept and development of many smart farm systems, usually linked to certain sector of agriculture (Idoje, Dagiuklas and Iqba, 2021; Lytos et al., 2020; Wolfert et al., 2017). These concepts try to reach the full control of entire production processes, minimizing the occurrence of potential production risks (mostly natural).



Picture 2. "Smart farm" concept
Source: IMP and IAE internal documentation.

During the period 2018–2021. IMP and IAE were developed, implemented and tested in practice the "Smart farm" concept at the previously selected small family farm located in Belegis, municipality of Stara Pazova. Farm is focused to crop production, mainly to vegetable growing. Implemented "Smart farm" concept involves totally automatized and remote controlled fert-irrigation system (with mutually independent irrigation lines based on the use of electromagnet valves) that encompass integrated energy plant based on RES (hybrid system that transforms solar and wind energy into the electric energy), digital weather station, certain sensors, farm surveillance system, etc. Concept provides optimal and prompt irrigation and fertilizing adjusted to crops needs (Picture 2). Installed power plant includes cointegrated solar panels (with output power of 8 kW), wind generator (0.5 kW) and battery bank (48 Vdc/720Ah). Implemented system is scalable and could be adjusted to any size of farm (Despotović, 2022; Despotović, Rodić and Stevanović, 2022).

Presented concept for farm management is excellent solution for small farmers that strives to overall automatization and remote management under their production process, as well to leave shallow environmental footprint. Elements included in investment analysis in line to implementation of mentioned concept are presented in next table (Table 2).

Table 2. Resume of the investment in implementation of the "Smart farm" concept applied in vegetable growing (in EUR)

No.	Element	
1.	Estimated value of investment (EUR)	
1.1.	Total investment	75,240.00
1.2.	Investment in fixed assets	68,400.00
1.3.	Investment in PWC	6,840.00
2.	Financing sources	
2.1.	Sources – total	75,240.00
2.2.	Own resources	24,240.00
2.3.	Other sources (subsidies)	51,000.00
2.4.	Interest or discount rate (%)	5 %
3.	Object of investment	
3.1.	Investment	Investment in implementation of "Smart Farm" concept
3.2.	Starting date of establishment	During 2019
3.3.	End date of establishment	During 2020
3.4.	Project economic life cycle (in line to usual credit line)	5 years
4.	Expected economic effects	

Table 2. Continued

No.	Element	
4.1.	*Static assessment*	
4.1.1.	Total Output-Total Input Ratio (%)	1.59
4.1.2.	Net Profit Margin (%)	33.27
4.1.3.	Accounting Rate of Return (%)	24.20
4.1.4.	Payback period	4 years and 1.57 months
4.2.	*Dynamic assessment*	
4.2.1.	Net present value	64,724.60
4.2.2.	Internal rate of return	28.42 %
4.2.3.	Payback period	4 years and 4.27 months
4.3.	*Break-even point analysis*	
4.3.1.	Break-even point (%)	0.16
4.3.2.	Rate of safety (%)	99.84

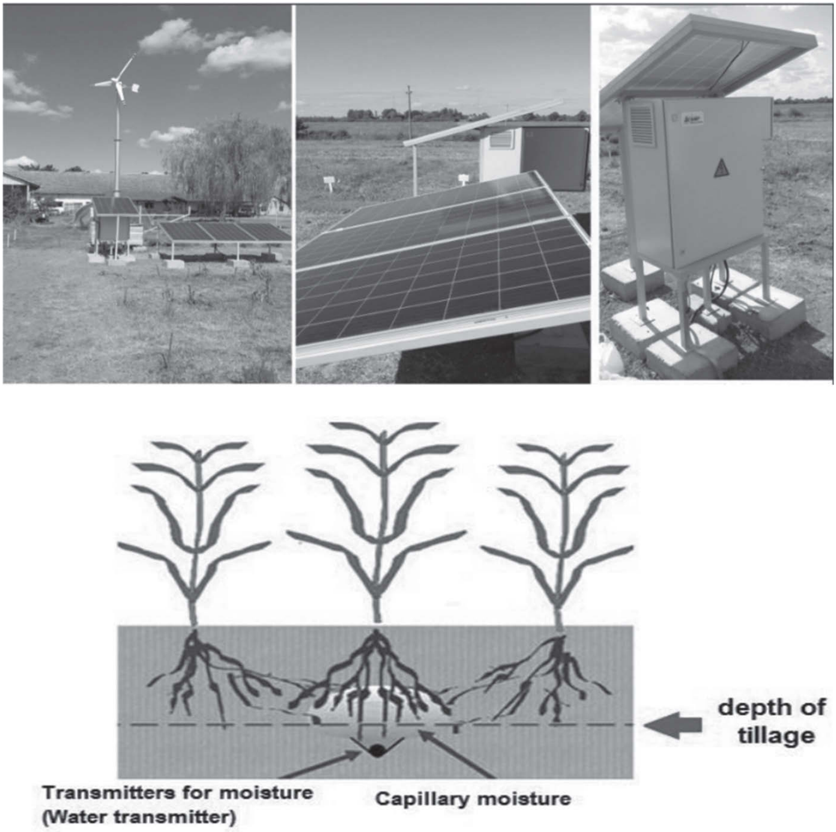
In accordance to performed investment analysis there is strong belief that implementation and exploitation of described concept based on RES use could be a good alternative not just for small vegetable producers.

"Agrokapilaris" irrigation system

Modern crop production that strives to reach high yields of hi-quality fruits is unimaginable without the use of irrigation (De Pascale et al., 2011). No matter the type of vegetable growing (in the field, or in protected area), there are in use different (under)ground irrigation systems (Incrocci et al., 2020; Zinkernagel et al., 2020).

During the season 2020/21, implementing team of the IMP and IAE Belgrade have been established the "Agrokapilaris" underground irrigation system in the green house (size of 0.05 ha) located at the experimental farm of the high agriculture-chemistry school from Obrenovac municipality, Belgrade. Contrary to usually use subsurface irrigation systems, in this case is implemented innovative subsurface capillary irrigation system. In line to its technical constructions, system belongs to highly precise (strictly controlled optimal water consumption) and smart technologies (it has self-regulation mechanism active in moment of water transfer to the plant).

System characterizes innovation contained in construction that involve a network of underground channels of small dimensions, made from unbreakable plastic foil, that has the shape of Latin letter V carrying the water transmitters with built-in elements for letting water in the system. Requirements for optimal volume of water is in the form of capillary moisture available to plant at any moment (Picture 3). Water is moving radially, ascending and laterally, without water losses, along the overall irrigation system and during the entire vegetation period. Wet front around the root system has the shape of ellipse with the center in moisture transmitter (Kljajić and Kovačević, 2021). So, "Agrokapilaris" is different from other available irrigation systems in next characteristics: operates under extremely low pressures (up to 0.2 bar); has long utilization period as the clogging of water transmitters is too rare; and has self-regulation according to transferred volume of moisture to plants. Interesting is that irrigation system is run by the use of RES (hybrid power system based on solar and wind energy), what gives it eco-friendly label. Energy system that powers the irrigation is consisted of four photovoltaic panels with power of 275 W each and wind turbine with power of 500 W, while they are connected to adequate battery bank and inverter.



Picture 3. "Agrokapilaris" concept
Source: IMP and IAE internal documentation.

In order to avoid stopping of the irrigation in circumstances of unfavorable weather conditions, system could be supplied by electric power from the public electro grid (Despotović, Rodić and Stevanović, 2021; Despotović and Stevanović, 2021).

Table 3. Resume of the investment in irrigation system powered by the RES used in irrigation of vegetables grown in greenhouse (in EUR)

No.	Element	
1.	Estimated value of investment (EUR)	
1.1.	Total investment	10,167.00
1.2.	Investment in fixed assets	9,243.00
1.3.	Investment in PWC	924.00
2.	Financing sources	
2.1.	Sources – total	10,167.00
2.2.	Own resources	10,167.00
2.3.	Other sources (subsidies)	–
2.4.	Interest or discount rate (%)	7 %
3.	Object of investment	
3.1.	Investment	Investment into the subsurface irrigation system with power plant based on RES
3.2.	Starting date of establishment	During 2020
3.3.	End date of establishment	During 2021
3.4.	Project economic life cycle (in line to usual credit line)	5 years
4.	Expected economic effects	
4.1.	*Static assessment*	
4.1.1.	Total Output-Total Input Ratio (%)	1.73
4.1.2.	Net Profit Margin (%)	35.81
4.1.3.	Accounting Rate of Return (%)	22.29
4.1.4.	Payback period	3 years and 8.72 months
4.2.	*Dynamic assessment*	
4.2.1.	Net present value	6,345.00
4.2.2.	Internal rate of return	23.51 %
4.2.3.	Payback period	4 years and 1.53 months
4.3.	*Break-even point analysis*	
4.3.1.	Break-even point (%)	7.83
4.3.2.	Rate of safety (%)	92.17

Offered solution provides shallow environmental footprint and high profitability, so it could be considered as highly justified option for wider exploitation at small and medium, or even larger farms. Summary of investment in implemented irrigation system and power plant based on RES (solar and wind energy) is presented in following table (Table 3).

In line to gained results, it could be concluded that implementation and exploitation of described irrigation system and energy powerplant based on RES could be a good business decision for the producers that grown the vegetable in protected area.

Solar dryer

In a broader sense, as a part of vegetable production chain, processing of vegetables could be also considered (Siddiq and Uebersax, 2018). It enables creation of the value added even at the farm level (Yadav, Tiwari and Khare, 2023). Among the available processing methods, vegetable drying is largely used in practice, as it provides gaining of well-preserved food products that have longer shelf life with minimized risks for adverse food quality changes (Jayaraman and Gupta, 2020). Usually used equipment for that purposes are driven on electricity from public power grid or on certain type of fossil fuel, while today is not so rare the implementation of engine system of dryer run by the energy gained from the renewable energy sources (RES) (Orsat, Changrue and Raghavan, 2006). Practically, due to general RES availability, as well as the plant complexity and level of initially required investment, the drying of plant material, including vegetables, is perfectly match the use of solar energy (Janjai and Bala, 2012). Besides economic and environmental benefits for the processor and near surrounding, this method provides the eco-friendly aspect for the produced final product (Prakash and Kumar, 2013).

Picture 4. Implemented solar dryer for plant species
Source: IMP and IAE internal documentation.

One of processing solutions for plant species drying (fruits, vegetables, medicinal herbs, spices, fungi's, etc.) based on the use of solar energy has been established and implemented by the IMP and IAE Belgrade at the experimental agricultural holding of the secondary Chemistry-agricultural school from Obrenovac municipality – Belgrade during the season 2022/23 (Picture 4).

Table 4. Resume of the investment in small processing plant for vegetable drying (in EUR)

No.	Element	
1.	Estimated value of investment (EUR)	
1.1.	Total investment	20,876.00
1.2.	Investment in fixed assets	18,979.00
1.3.	Investment in PWC	1,897.00
2.	Financing sources	
2.1.	Sources – total	20,876.00
2.2.	Own resources	17,812.00
2.3.	Other sources (subsidies)	3,064.00
2.4.	Interest or discount rate (%)	5 %
3.	Object of investment	

Table 4. Continued

No.	Element	
3.1.	Investment	Investment into establishment of solar dryer
3.2.	Starting date of establishment	During 2022
3.3.	End date of establishment	During 2023
3.4.	Project economic life cycle (in line to usual credit line)	5 years
4.	Expected economic effects	
4.1.	*Static assessment*	
4.1.1.	Total Output-Total Input Ratio (%)	1.20
4.1.2.	Net Profit Margin (%)	30.81
4.1.3.	Accounting Rate of Return (%)	11.63
4.1.4.	Payback period	4 years and 3,58 months
4.2.	*Dynamic assessment*	
4.2.1.	Net present value	6,489,40
4.2.2.	Internal rate of return	13.65 %
4.2.3.	Payback period	4 years and 6,06 months
4.3.	*Break-even point analysis*	
4.3.1.	Break-even point (%)	3.06
4.3.2.	Rate of safety (%)	96.94

Dryer facility is fully automatized and remote controlled, while it has possibility for the energy storing, as it implies drying chamber with installed fans and chamber for storing (thermal buffer – space coated by chamotte) of unused heat energy in processing activities that could be later used for warming or cooling some other facilities at the holding (e.g. greenhouse, offices, veterinary clinic, stables, warehouse, etc.). Use of energy surplus derived from processing affects annual power costs cut for the holding equivalent to 7,200 KW. Contrary to that, in any time, short-term deficiency of solar (heat) energy could be changed with electricity from public power grid. General energy capacity of the installed mini solar dryer is about 3.5 KW, while the drying capacity is 100 kg of vegetables in one cycle of drying. Complete cycle of drying lasts for 48 hours. Established plant is initially projected for small farmers, but plant is scalable, so it could be projected for larger producers too. Installed plant could be used for over the 40 years, while its implementation requires several months.

Offered solution is subject of supporting measures at national level (maximally 50 % of the investment without VAT). In sense of ecology and economy it represents highly justified alternative that could be widely used at small scale farms. Summary of investment in installed processing plant is given by the next table (Table 4).

According to assumed elements of establishment and the use of solar dryer, and gained indicators for the assessment of the economic effectiveness of investing in the mentioned alternative, the implementation and exploitation of the solar dryer would be a reasonable business decision for the investor. Of course, it has be noted that smaller part of the investment is financially supported.

Conclusions

Vegetable growing has great importance for humans and sector of agriculture, as it supplies the human population with essential, high quality nutrients, contributes to crop rotation and making value added at the farm level, preserves the income and livelihood of farm members and rural population, etc. While performing the vegetable growing, farm should strive to keep all tree axes of sustainability. In other words, it has to secure continuity in volume and quality of produced food products, or to assure that farm's activities leave the shallow environmental foot print, as well as to adequately employs internal and external labor and contributes to development of local rural community.

Mentioned could be partly fulfilled by implementation and use of innovative technological and technical alternatives, adequate production procedures, and organizational and quality schemes, etc. In other words, farm could deeply lean on available knowledge, or could make stronger links to scientific and professional institutions towards the taking over existing, or designing and further development of particular elements of production base potentially used at farm estate. These strivings, and potentiation of making bridges between the knowledge and production, have to be also recognized by policy makers, providing further support for implementation of advanced tech-tech solutions that will boost the overall sustainability at the farms.

In line to primary goal of research, there are presented certain technical characteristics and economic effects gained from the investment in utilization of few hi-tech alternatives based on the RES use in vegetable production and processing. So, investment analysis of the implemented Solar mobile robotized electro-generator, "Smart farm" concept, "Agrokapilaris" irrigation system, or Solar dryer shows that all alternatives could be considered economically and environmentally justified to be used at farm level.

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