Environmental and Economic aspects of PVWP system.

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Abstract: *A lot of techno-economic analyses have been conducted to seek the most cost-effective solution for irrigation purposes applied in the interval time of 25 years of project life. The possible benefits outlined by the PVWP system implementation have been identified, as well as the effects of the most sensitive parameters, such as installation price, incentives and other credit options such as carbon credit rate or feed in tariff. The output carried out from the simulation shows that PVWP system represents the best solution to provide free carbon and costless electricity to run the water pump for sprinkler irrigation in the agriculture sector in Albania. The environmental benefits have been also addressed, evaluating the CO_2 emissions saving achievable from the PVWP system operation and some financial aspects such as simple payback period (SPP), NPV and the carbon footprint reduction per ha. As a conclusion replacement of diesel-powered water pumping used only for irrigation purposes results in an annual net reduction of CO_2 emissions by 1.9416 ton per year which is equivalent to 861 litres of gasoline not burned. The net specific GHG reduction results 0.09708 $kgCO_2/m^2$, simple payback period results 5.7 year and Net Present Value (NPV) 4961.74€ and by applying a Feed-in tariff 0.0600 €/m³ then the water sale income results 19 817 € for the entire project life of 25 years starting from 2022.*

Keywords: *PVWP, RETScreen Expert, CO_2, SPP, Irrigation*

1. Introduction

Existing 2030 climate and energy framework and ambition aims to cut at least 40% in GHG from 1990 levels; at least 32% share for renewable energy and at least 32.5% improvement in energy efficiency. Despite cost declines and continuous policy support, faster wind growth hinges on resolving social acceptance, permitting and grid integration problems [1]. During the last 10 years, the incremental costs and benefits of irrigation have changed, as have public preferences regarding the allocation of water among agricultural, municipal, and environmental uses. The use of PVWP technology for irrigation is considered an innovative and sustainable solution with the aim to provide cost-effective solution within off grid PV concept. Such systems can promote the use of agriculture land, especially in remote areas of Albania. The combination of PVWP technology with water saving irrigation techniques and sustainable management of the groundwater resources can lead to several benefits. The integration of distributed renewable energy in agriculture sector can bring a lot of economic benefits to the farmers including the reduction of energy use per unit and also can help the mitigation of GHG emissions. This paper assesses the possibility of installing PVWP system at one site of an existing Greenhouse. Hence, to estimate the potential of integrating solar into the country's energy mix. The RETScreen software is used for the feasibility and financial viability evaluation. The study found out that the Divjaka municipality part of the Fier county experiences the highest solar irradiation as it recorded 4.56 kWh/m^2/day. The financial indicators like the internal rate return, equity payback years, cumulative cash flows and simple profitability index all indicated that the agriculture sector is the best option for the development of solar energy and GHG potential reduction. The impact of the development of these plants will also have a considerable impact on the environment since the research on the field shows a great potential in the reduction in the emission of greenhouse gases (GHG), in some cases around 93%. Such systems are foreseen to play a key role in a stable, costless and emission-less way especially in off-grid applications. The performance, availability, costs and carbon intensity of photovoltaic power all indicate that this technology can make a very substantial contribution to reduce carbon emissions and gain carbon credits.

Similarly, in the study of [2] it is shown that Off-grid PV concept applied in telecommunication sector can bring a lot of benefits. Hence, PVWP systems can be used in the agriculture sector for irrigation purposes.

In the other hand the depletion of fossil fuel and the negative effect on the environment as well as the potential techno-economic merits of "*hybrid combinations*" identified as a good solution moving towards reliable and more feasible energy systems based on renewables [3]. As the need for clean, sustainable energy increases, and renewable technologies get ever more advanced, more projects had been developed in greater sizes and complexities, including on-grid and off-grid solutions based on renewables.

Using solar PV to power mini-grids is an excellent way to bring electricity access to people who do not live near power transmission lines, particularly in developing countries with excellent solar energy resources and reducing the negative effect on environmental.

2. Site background and installation of proposed PV-Water pump station

In our case study the installation place will be located in Divjaka (41°02'158"N and 19°53'26"E) as it is shown in figure 1. The area has an altitude of 90 m above sea level and the measured average annual air temperature results 15.24^{o}C. Atmospheric mean pressure value and wind velocity measured at 10m altitude results 97.38kPa and 1.1 ms^{-1}.

Figure 1: The property of the proposed PVWP location.

The property area chosen for this case study is around 2.0 ha and has an existing water well of 5 m deep. The water quantity is provided from the well is enough to irrigate that surface for 8 hours up to level 0.5 m.

The property has installed a greenhouse with a surface of 0.5 ha usually used for potatoes, tomatoes and carrots. Daily water amount for irrigation depends on weather condition and temperature. The mean earth temperature varies from 5.6^{o}C in January up to 25.26^{o}C in August while precipitation varies from 25.73mm in July up to 118.5mm in November.

3. *Materials and methods*

Actually, there are several models available for conducting a set of analysis including environmental impact and benefits. RETScreen Expert is a clean-energy awareness, decision-support and capacity-building tool [4]. This model helps us as energy planers to determine the annual reduction in the emission of greenhouse gases stemming from using the proposed technology in place of the base case technology. The model uses a computerized system with integrated mathematical algorithms and top to bottom approach which has been developed to overcome the barriers to clean energy technology implementation at the preliminary feasibility stage. It provides a cost analysis, GHG emission reduction analysis, financial summary, sensitivity analysis, provides a low-cost preliminary assessment of RES projects with a small set of a detailed information. Methodology 2 as the more suitable to perform the techno-economic analysis is chosen [5]

4. Off - Grid PV systems applications

Off grid PVWP systems applications have been studied to cover a lot of issues, especially to provide water for drinking purposes in the areas that suffer the lack of electricity. Nevertheless, the drastic fall in prices of PV modules due to the new-born production and costless technologies of the PV lead to increased interest on research and development of off grid PV systems, encouraging greater system flexibility and large-scale integration and new applications especially in Albania. The research is mainly focused on system design, optimization of system components (such as BOS and solar array performance), and technical and economic comparisons between PV and other traditional stand-alone fossil powered sources. The studies have demonstrated that a solar PV combined with diesel engine (hybrid) has relatively lower LCOE than a pure diesel generator-only. The IEA estimates that to achieve the goal of universal electricity access, 70% of the rural areas that currently lack electricity will need to be connected using mini grid or off-grid solutions. Photovoltaic systems can be combined with fossil fuel driven (Genset) motors. Off-grid applications include both stand-alone systems, and hybrid systems, which are similar to stand-alone systems but also include a fossil fuel generator (Genset) to meet some of the load requirements and provide higher reliability. The studies have demonstrated that a solar PV combined with diesel engine (hybrid) has relatively lower LCOE than a pure diesel generator-only. Nevertheless, the capital cost of the battery, which is one of the most significant components in LCOE evaluation aims to be reduced to more than 60% by 2030 [6]

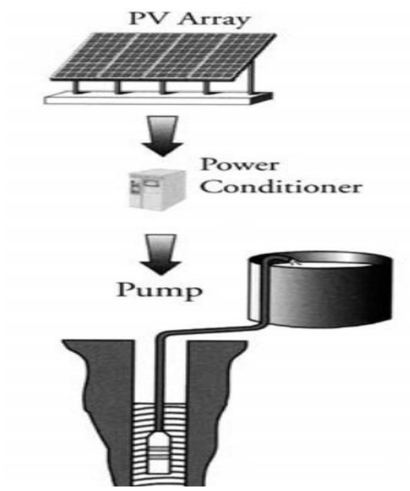

Figure 2: Schematic representation of a PVWP system [5].

PVWP application in agriculture sector can bring and provide water for irrigation purposes. This solution represents an alternative to simplify the installation process and to facilitate the independent electricity anywhere, reducing the cost of electrical wiring network infrastructure and design, installation time and maintenance. Other important outcomes from this proposed system are as below:

- Greater accessibility to equipment,
- Reduced time for flaws detection and reducing visits to the site. The perspective of a wide use of green power motivates the scientific community to study the possibility of fabricating hybrid-PV modules providing autonomous electricity station especially in remote areas.

RETScreen Expert, an advanced computer software which a basic energy model used for small different off-grid PV configurations is chosen.

5. Emission reduction analysis in RETScreen Expert model

The model performs a GHG emission reduction analysis depending on whether the clean energy system under consideration generates electricity or provides other energy requirements.
The only difference lies in transmission and distribution losses, which are incurred only by electricity generating systems. The reduction Δ_{GHG} is calculated as follows in equation 1:

$$\Delta_{GHG} = \left(e_{base} - e_{prop}\right) E_{prop}(1-\lambda_{prop})(1-e_{cr}) \quad (1)$$

where e_{base} is the base case GHG emission factor, e_{prop} is the proposed case GHG emission factor, E_{prop} is the proposed case annual electricity produced, λ_{prop} is the fraction of electricity lost in transmission and distribution for the proposed case, and e_{cr} the GHG emission reduction credit transaction fee. For both the base case and proposed case system, the transmission and distribution losses are deemed to be negligible for on-site generation, such as off-grid and water-pumping PV applications.

6. GHG emission factor – base case electricity system

For the base case electricity generation system is strictly required the calculation of the GHG emission factors, defined as the mass of greenhouse gas emitted per unit of energy produced. For a single fuel type, the following formula in equation (2) is used to calculate the base case electricity system GHG emission factor, e_{base}:

$$e_{base} = \left(e_{CO_2} GWP_{CO_2} + e_{CH_4} GWP_{CH_4} + e_{N_2O} GWP_{N_2O}\right) \frac{1}{\eta}\frac{1}{1-\lambda} \quad (2)$$

where e_{CO2}, e_{CH4}, and e_{N2O} are respectively the CO_2, CH_4 and emission factors for the fuel/source considered, GWP_{CO2}, GWP_{CH4}, and GWP_{N2O} are the global warming potentials for CO2, CH_4 and N_2O, η is the fuel conversion efficiency and λ is the fraction of electricity lost in transmission and distribution. The GHG emission factor will vary according to the type and quality of the fuel, and the type and size of the power plant. In cases for which there are a number of fuel types or sources, the GHG emission factor e_{base} for the electricity mix is calculated as the weighted sum of emission factors calculated for each individual fuel source given in equation (3):

$$e_{base} = \sum_{i=1}^{n} f_i e_{base,i} \quad (3)$$

where n is the number of fuels/sources in the mix, f_i is the fraction of end-use electricity coming from fuel/source i, and e_{base}, *i* is the emission factor for fuel *i*, calculated through a formula similar to equation (2):

$$e_{base,i} = \left(e_{CO_2,i} GWP_{CO_2} + e_{CH_4,i} GWP_{CH_4} + e_{N_2O,i} GWP_{N_2O}\right) \frac{1}{\eta,i}\frac{1}{1-\lambda,i} \quad (4)$$

where $e_{CO_2,i}$, $e_{CH_4,i}$ and $e_{N_2O,i}$ are respectively the CO2, CH4 and N2O emission factors for fuel/source i, η,i is the fuel conversion efficiency for fuel i, and λ,i is fraction of electricity lost in transmission and distribution for fuel i.
The GHG emission factor for the electricity mix will apply from year 1 up to the year of change in baseline, as specified by the user, unless no changes are specified; in this case, the emission factor will apply throughout the life of the project. When a change in the baseline emission factor is specified, the new factor for the year that the change in baseline takes place, and the years that follow will be determined by (e*):

$$e^{*}_{base} = e_{base} r_{change} \quad (5)$$

where r_{change} is the percentage change in the base case (baseline) GHG emission factor for the year that the change in baseline takes place, and the years that follow.

7. GHG emission factor – proposed case electricity system

The calculation of the proposed case electricity system GHG emission factor, e_{prop}, is similar to that of the base case GHG emission factor, with the exception that for off-grid systems the fraction of electricity lost in transmission and distribution is set to zero. e_{prop} is therefore calculated through equation (2) with λ=0, in the case of a single fuel/source, or through equations (3) and (4) with all λ_i=0, in the case of a mix of fuel/sources.

8. Silmulation of the PVWP system in RETScreen Expert

Emission factors will vary for different types and qualities of fuels, and for different types and sizes of power plants.. The electricity mix factors thus account for a weighted average of the fuel conversion efficiencies and T&D losses of the different fuel types. For fuel type selected, diesel 2, 100% single fuel mix, units are given in (kg/GJ) as it is shown in table 2.

Table 2: Emission factors for the chosen fuel type taken in the study (Diesel#2)

Fuel Type (Base case)	Fuel Mix	CO_2 emission factor (kg/GJ)	CH4 emission factor k(g/GJ)	N2O emission factor (kg/GJ)	Electricity Generation efficiency (%)	T&D losses (%)	GHG emission factor (tCO2/MWh)
Fuel Mix (%)	100	70	0.002	0.0006	35	7	0.777
Electricity Mix (%)	100	215	0.0063	0.0018		7	0.777

In the baseline case the diesel 2 fuel type is chosen in the simulation of the system. A typical Genset could have an electricity generation efficiency of 35% and CO_2 emission factor results 70kg/GJ. Specific emission factor for N_2O for the selected fuel type is 0.0006 kg/GJ resulting to 0.0024 kg/GJ and 0.0063 kg/GJ of CH_4.

The GHG emission factor results 0.777 tCO_2/MWh including 7% T&D losses.

Table 3: Calculation of CO_2, CH_4 and N_2O for the base case system.

Fuel Type (Baseline GHG Summary)	Fuel Mix	CO_2 emission factor (kg/GJ)	CH4 emission factor (kg/GJ)	N2O emission factor (kg/GJ)	Fuel consumption (MWh)	GHG emission factor (tCO2/MWh)	GHG emission (tCO2)
Electricity	100%	297.8	0.0063	0.0018	2.6	0.777	2

In the table 3 the GHG emission for the base case system by multiplying the fuel consumption by the GHG emission factor. The model also calculates the GHG emission for the base case system by multiplying the annual system losses by the global warming potential. The total gross annual GHG release in environmental results 2.0127tCO_2.

9. GHG reduction credit

In this case study the optional GHG reduction credit, per equivalent ton of CO_2 (tCO_2) is considered. It is used in conjunction with the net GHG reduction to calculate the annual GHG reduction revenue. Prices for GHG reduction credits, per equivalent ton of CO_2 (tCO_2), vary widely depending on how the credit is generated and how it will be delivered. Other factors which have an impact on price may include voluntary or mandatory emissions reduction; private or public purchase of credits; credits traded within, for example, the European Union Greenhouse Gas Emission Trading Scheme (EU ETS), other national, transnational, or regional schemes; type of technology used to generate the emissions reductions; and others. As of May 2014, prices including rates for carbon taxes varied between $1 to $168 per ton of CO_2 [7].

The model escalates the GHG reduction credit rate yearly according to the GHG reduction credit escalation rate starting from year 1 and throughout the GHG reduction credit duration as it is given in the table 4.

Table 4: Calculation of the carbon credit revenue

	$/tCO2	*25*
GHG reduction credit duration	Yrs.	25
GHG reduction credit escalation rate	%	2
Gross annual GHG emission reduction	tCO2	0.3203
GHG credits transaction fee	%	2
Net annual GHG emission reduction	tCO2	1.9416
GHG reduction revenue	$	48.5

Carbon credit instruments often coexist with other heterogeneous policies that may directly or indirectly contribute to reducing GHG emissions by addressing areas such energy or infrastructure. In our study they have to be planned to interact and complement other strategic priorities at local and national levels. The GHG reduction credit duration is acceped to be applied all into the whole lifetime of the proposed PVWP system with a reduction credit escalation rate of 2%. From the calculation the net annual GHG results 1.9416tCO_2 leading to 48.5$ of GHG reduction revenue. The credit transaction fee is accepted 2%. In the graph in figure 3 the results of the simulations of the hybryd system compared to that of the base case (diesel powered water pump alone) is given. The proposed system, hybrid PV offers the lowest possible scenario for the mitigation of GHG emissions resulting to 0.0315tCO2 compared to baseline scenario 2.0127tCO_2.

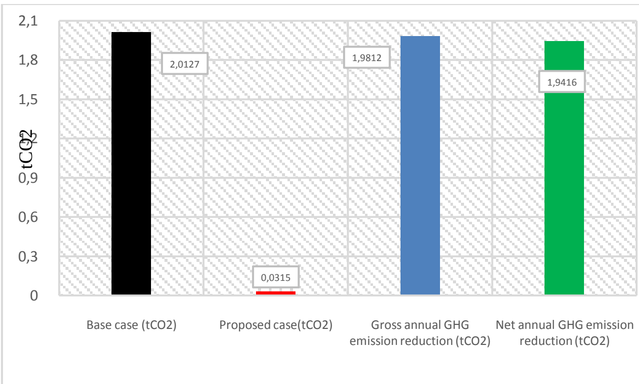

Figure 3: Results of the simulation of the baseline scenario and PVWP system.

The simulation shows that an amount of 1.9416 tCO_2 is reduced by the proposed PVWP system equivalent to 851 litres of gasoline not used or 0.4503 acres of forest absorbing carbon.

10. Financial analysis of the proposed PVWP system.

Simulation period		*25*
Project life	yrs.	25
Inflation	%	3
Discount rate	%	8
Water sale	€/m^3	0.06
Payback period	yrs.	5.7
NPV	€	4961.74
Yearly Water income (After-tax-profit)	€	793
GHG reduction revenue	$	48.5

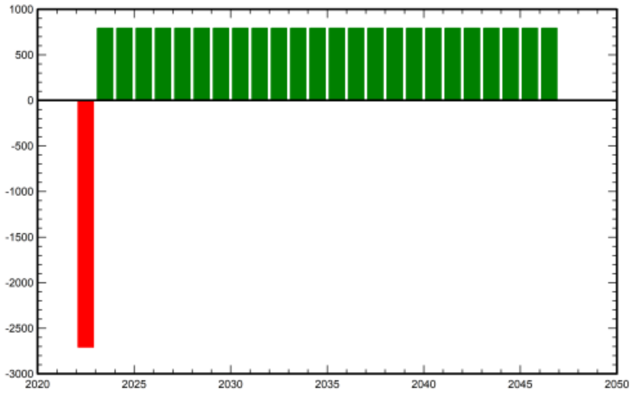

Figure 4: Cumulative cashflow (€)

In figure 4 cumulative cash flow is represented. The model calculates the cumulative cash flows, which represent the net pre-tax flows accumulated from year 0 (refering to 2022). The net pre-tax cash flows are the yearly net flows of cash for the project before income tax. It represents the estimated sum of cash that will be paid or received each year during the entire life of the PVWP project. Annual costs, savings and revenue, which reflect amounts valid for year 0, are thus escalated one year in order to determine the actual costs and savings and revenue incurred during the first year of operation. The cumulative cash flows are plotted versus time in the cash flows graph in figure 4. In the case study the total investement cost (exluding water tank and well) for the PVWP system cost is conidered 4500€.

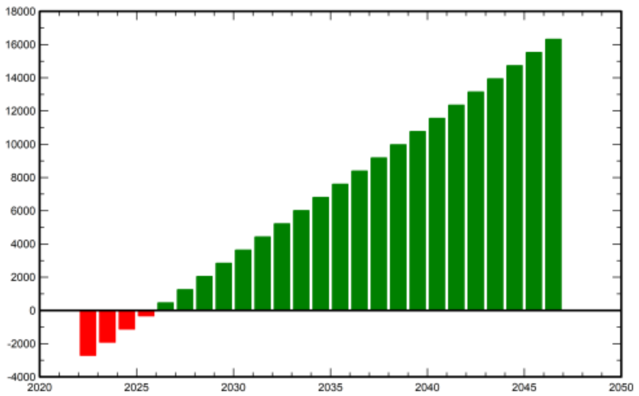

Figure 5: Simple Payback (years).

A lot of studies have been performed regarding economic aspects of PV systems. In the study of [8-9] Life Cycle Assessment of Photovoltaics Energy Payback Time Mono is analyzed. The simple payback should not be used as the primary indicator to evaluate a project. It is useful, however, as a secondary indicator to indicate the level of risk of an investment. A further criticism of the simple payback method is that it does not consider the time value of money, nor the impact of inflation on the costs. On the other hand, the payback period is often of great importance to individuals or small firms that may be cash poor. In our study the payback period results 5.7 years.

11. Conclusion

The present paper has identified various aspects related to PVWP system for an autonomous water supply in Divjaka region, including an universal understanding of the GHG emission mitigation process. The existing diesel water pump generators can be substituted by applying photovoltaic (PV) technology which can be combined in perfect harmony as the maximum solar radiation falls in the same period when water demand is high. In this paper, the feasibility of a single integrated autonomous PVWP system, discussing its potentiality in agriculture sector is analyzed.

As a conclusion replacement of diesel-powered water pumping used only for irrigation purposes results in an annual net reduction of CO_2 emissions by 1.9416 ton per year which is equivalent to 861 litres of gasoline not burned. The net specific GHG reduction results 0.09708 kgCO2/m2, simple payback period results 5.7 year and Net Present Value (NPV) 4961.74€ and by applying a Feed-in tariff 0.0600 €/m³ then the water sale income results 19 817 € for the entire project life of 25 years starting from 2022.

The outputs of the study can be used by policymakers in the country in the way in the decarbonization of the energy sector, especially the agriculture sector, fully based on fossil fuel (73%).

References

[1] IEA (2020), Renewables 2020, IEA, Paris https://www.iea.org/reports/renewables-2020

[2] Malka, L., Gjeta, A., Konomi, I., Alcani, M., Bebi, E., & Kaci, S. (2020). Off-grid hybrid PV configuration' s role to supply internet access points antenna in remote areas. Case study: " Ostren i vogël - Trebisht " villages, Bulqiza district, Albania. 226(5), 218–226 https://stumejournals.com/journals/i4/2020/5/218

[3] IEA, "World Energy Investment 2019 Edition," (2019) and Sawle Y 2017 Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system Renewable and Sustainable Energy Reviews 81(2) 2217-35 http://dx doi org/10 1016/jrser 2017 06 033

[4] RETScreen. Financial and risk analysis, 2004. Retrieved: July 20, 2015 from http://www.retscreen.net/ang/financial_and_risk_analysis_with_retscreen.php

[5] Malka, Lorenc et al. 2020. "An Approach to the Large-Scale Integration of Wind Energy In." 10(5): 327–43 https://www.econjournals.com/index.php/ijeep/article/view/9917/5291

[6] IRENA, Electricity storage and renewables: Costs and markets to 2030, (2017)

[7] World Bank. 2014. State and Trends of Carbon Pricing 2014. Washington, DC: World Bank

[8] Nelson, Jenny, Ajay Gambhir, and Ned Ekins-daukes. 2014. "Solar Power for CO2 Mitigation"(11).

[9] Wild-scholten, Mariska De. 2013. "Life Cycle Assessment of Photovoltaics Energy Payback Time Mono." (October)