On-site Production of Electricity and Hydrogen for the Energy Needs of Rural Areas

Javier Carroquino, University of Zaragoza, Spain
Jesús Yago, Intergia energía sostenible S.L., Spain

The European Conference on Sustainability, Energy & the Environment 2017
Official Conference Proceedings

Abstract
In both developed and developing countries, energy supply in rural areas is needed in an economical and environmentally sustainable way. On the one hand, extensions of the power grid are often inadequate due to their high cost and impact on the landscape. On the other hand, diesel generator sets have high greenhouse gas emissions and other undesirable environmental impacts. As a result, on-site renewable energy generation becomes the best option. The two main types of energy required are electricity for stationary uses and diesel for mobility. Therefore, the European project LIFE REWIND proposes the implementation of off-grid renewable energy systems, producing both electricity and hydrogen. A prototype has been designed and installed in a vineyard, to carry out the validation in a real case. It includes three photovoltaic sets: one is on the terrain, another is floating on an irrigation pond and the last one is on a solar tracker. The electrical system is configured as a micro-grid, with the same characteristics of the utility grid. The electricity is supplied to a wastewater treatment plant, a drip irrigation system and other uses like air conditioning and lighting. Moreover, with the surplus energy, an electrolyser produces hydrogen by electrolysis of water. An off-road vehicle with a fuel cell feeds on that hydrogen and carries people around the vineyard. In conclusion, electricity and hydrogen are produced from renewable resources on the farm itself. In addition, it is expected to obtain positive effects on the rural economy and employment.

Keywords: renewable energy, photovoltaic, hydrogen, irrigation, fuel cell, CO_2 emissions.

Introduction

Combustion of fossil fuels to produce energy is the major source of CO_2 emissions and the main cause of the greenhouse effect (EEA, 2016). To avoid this, it is necessary to drastically reduce the use of coal, oil and natural gas, replacing them with renewable energy sources. On the one hand, developed countries must make changes and investments to replace the sources of the large amount of energy they consume. Two difficulties they have for this are the high energy intensity of their economy and the resistance to change of some sectors involved (Yaqoot, Diwan, & Kandpal, 2016). On the other hand, developing countries still have the challenge of bringing energy to their entire population, even in remote areas (External, Of, & Union, 2014). In this case, a weak public power grid and large transport distances are costly obstacles. There are many studies proposing the use of renewable energy systems for the supply of electricity in developing areas (Hao, Li, Cao, & Ma, 2016). The proposed technical solutions are mainly stand-alone generation or micro grids, avoiding the need to expand the public electrical grid. By contrast, in developed countries, the electricity supply in rural areas is expected to be done with extensions of the grid. Only when the cost is very high, another solution is taken into account. However, in both developing and developed countries, an energy supply with low environmental and landscape impacts is needed in natural or rural areas. Another issue which is often addressed differently in developed or developing countries is the effect of the solution adopted on the local population. Regarding developing countries, several approaches (Bhattacharyya, 2012) consider imperative not only that the concerned rural communities accept the proposed solutions, but also their involvement in the maintenance work. In contrast, in developed countries, no one shows an interest in the effect on the local population of how energy is supplied. As a result, the opinion of the affected population is not taken into account and even the opportunity to create local employment is lost. To summarize, despite the differences, in both developed and developing countries, the way of supply of electricity in rural and natural areas may be chosen with a focus not only technical but also environmental and socioeconomic.

A very important demand for energy in rural areas, with its related CO_2 emissions, comes from agricultural activities (Lal, 2004)(Schneider & Smith, 2009). Usually, electricity is obtained from the grid or is produced on site by diesel generator sets. Its replacement by renewable energy could minimize the environmental impacts. As for the agricultural machinery, it is also necessary to reduce its CO_2 emissions, derived from diesel combustion (Moreda, Muñoz-García, & Barreiro, 2016). In addition, if on-site generation is incorporated in rural areas, it is possible to obtain a positive socioeconomic impact in the areas involved (Goel & Supriya, 2015).

The LIFE REWIND project

The full name of the European project LIFE REWIND is "Profitable small scale renewable energy systems in agrifood industry and rural areas: demonstration in the wine sector". This project has carried out a holistic approach to energy supply in rural areas. Although their focus has been the energy needs of agricultural activities, especially vine-growing (Carroquino, Dufo-López, & Bernal-Agustín, 2015), very similar techniques can be applied to power supply in any remote area. Furthermore, vine growing and wine making are among the activities most sensitive to climate change (Mozell & Thach, 2014). The challenge is to produce energy where it is needed, where the power grid does not reach, safely and at a reasonable cost. In the absence of the electricity grid, energy production must be well adapted to demand. If more energy is produced than necessary, it will be wasted. In addition, if production is not simultaneous with consumption, it will need to be stored. Consequently, a good characterization of the energy demand is necessary to find the optimum size of the generation system, including the batteries. Thus, the first step is to obtain information on demand and other factors to take into account. Table 1 shows the data groups and the sources where they were obtained.

Table 1 Data collection (energy and resource)

Data sources	Data sets
Electricity bills	Historical electricity consumption
	Electricity prices
	Seasonality of the demand
Fuel delivery notes and user annotations	Historical fuel consumption
	Maintenance costs
Market prices	Installation investment cost
Interviews and Surveys	Demand side manageability
	Needs and criteria of operation
	Attitude about sustainability
On site measurements	Powers and consumptions
Photovoltaic Geographic Information Systems	Solar resource
Bibliographic databases	Wind resource
On-site measurement campaigns	Solar resource
	Wind resource
	Temperatures

Both objective and subjective data, including the attitude towards environmental sustainability, have been obtained in the Spanish wine sector. One of the objectives is to know the difficulties and motivations that affect the incorporation of renewable energy. The methodology used for the surveys has been carried out in three stages. A first exploratory phase, through semi-structured and directed interviews that were used as tests of the questionnaire or pre-test. A second stage in which the final questionnaire has been developed and the type of sampling has been designed. And a third phase that has been dedicated to the statistical analysis of the data provided by the survey to draw conclusions and to be able to make the right decisions. In order to simplify the sampling procedure to the maximum extent while preserving the representativeness of the sample, it was decided to use a simple random sampling and, subsequently, a stratification by administrative region. A detailed explanation of the methodology used in the surveys, as well as the results, will be the subject of a specific publication.

Regarding renewable resources, the European online Photovoltaic Geographic Information System (PVGIS) has been used to quantify the geographical distribution of solar resources in different areas studied. In five case studies, including that for the location of prototypes, two-year measurement campaigns have been carried out for the on-site measurement of renewable resources. Each measuring station incorporates wind sensors (two anemometers and a wind vane), a solar irradiation sensor (pyranometer), a data-logger, an autonomous power system with solar panel and a data transmitter. The dataset obtained allows the characterization of the solar and wind resources in the studied areas, mainly southern Europe.

Once the data on available renewable resources and energy demand have been characterized, several kinds of facilities have been identified, corresponding to winery, pumping for irrigation and, in addition, farms and other agricultural activities. All of them have been studied to a greater or lesser degree. Obviously, the case where the prototype was installed was analysed in depth.

One of the actions carried out by the project is the design and assembly of a prototype that supplies renewable energy produced on-site for a vineyard and a winery. The prototype has a dual role in the project. On the one hand, it is a demonstration facility and prepared to be visited and shown to stakeholders. On the other hand, the data obtained from its operation will allow us to carry out a thorough technical and economic study. The design of the renewable generation system has been performed by heuristic methods. For this purpose the iHOGA program was used, which is a software tool based on genetic algorithms (Bernal-Agustín & Dufo-López, 2009). Firstly, sets of simulations and optimizations have been performed, in search of the best configuration and size, both from an economic and emission reduction point of view. Secondly, the prototype has been designed and installed. Thirdly, it is being used for the validation in a real case. Finally, throughout a year of operation, various technical and economic parameters are being measured for further analysis.


Figure 1 Floating photovoltaic set and solar tracker photovoltaic set

The chosen generation technology has been photovoltaic, for having an annual profile compatible with the energy demand of the irrigation and winery. The prototype includes 43.2 kWp of photovoltaic panels, distributed in three sets. The first one is mounted on a fixed structure on the terrain, which is the simplest solution. Its fixation on the ground has been made using prefabricated blocks of concrete, which can be placed and removed without environmental impact in the place. The second set (Figure 1) is floating on an irrigation pond. This innovative solution saves the use of land, its preparation and the placement of the fence (Sahu, Yadav, & Sudhakar, 2016).

The floating system has been specifically designed for use in irrigation ponds, adapting to its frequent filling and emptying. The last set is mounted on a solar tracker (Figure 1). As it is permanently oriented towards the sun, this solution offers a greater production of energy. Figure 2 shows the production of the set on the fixed structure and Figure 3 of the set on the solar tracker, for the same day. On the one hand, this variety of mounting systems allows visitors to see different options. On the other hand, it allows for the collection of data that will be used for technical and scientific comparatives.

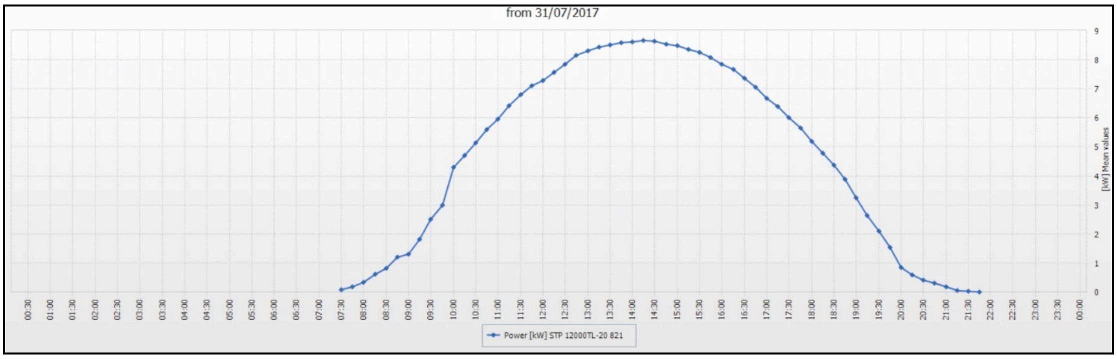

Figure 2 Production of the photovoltaic set on the fixed structure, on 07/31/2017

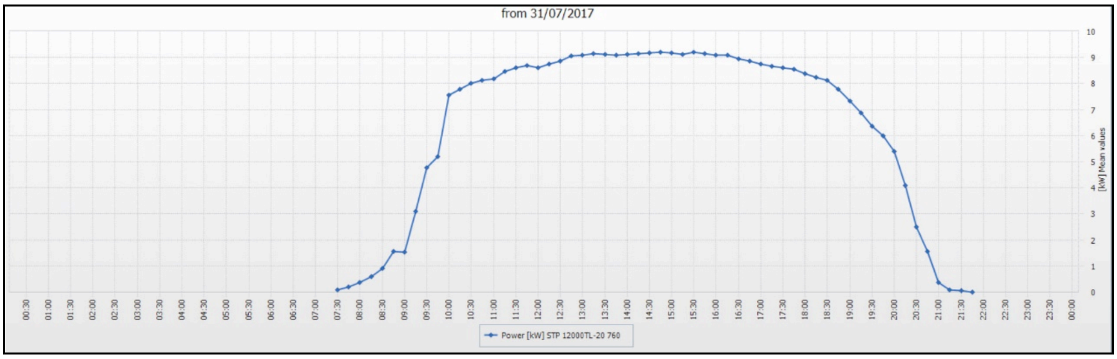

Figure 3 Production of the photovoltaic set on the solar tracker, on 07/31/2017

Regarding the stand alone electrical system, a three-phase AC 400 V 50 Hz bus has been chosen, produced by three inverters that manage a set of batteries of 48 V 2,680 Ah C10. The energy produced by the three photovoltaic fields is injected into the AC bus via three three-phase solar inverters. Thus, the electrical system is configured as a micro-grid, with the same characteristics of the public electrical grid. The electricity is supplied to the wastewater treatment plant of the winery, a drip irrigation pumping system and other uses like air conditioning and lighting. It is remarkable to note that the wastewater from the winery, after its treatment, is used for irrigation. Furthermore, with the surplus energy, an electrolyser produces hydrogen by electrolysis of water, which is then compressed to 200 bar and stored (Figure 4). An electric off-road vehicle has been adapted, by incorporating a fuel cell system and carries people around the vineyard (Figure 5). Thus, the vehicle feeds on hydrogen produced in the vineyard itself. The whole process is 100% clean and operates without emissions.

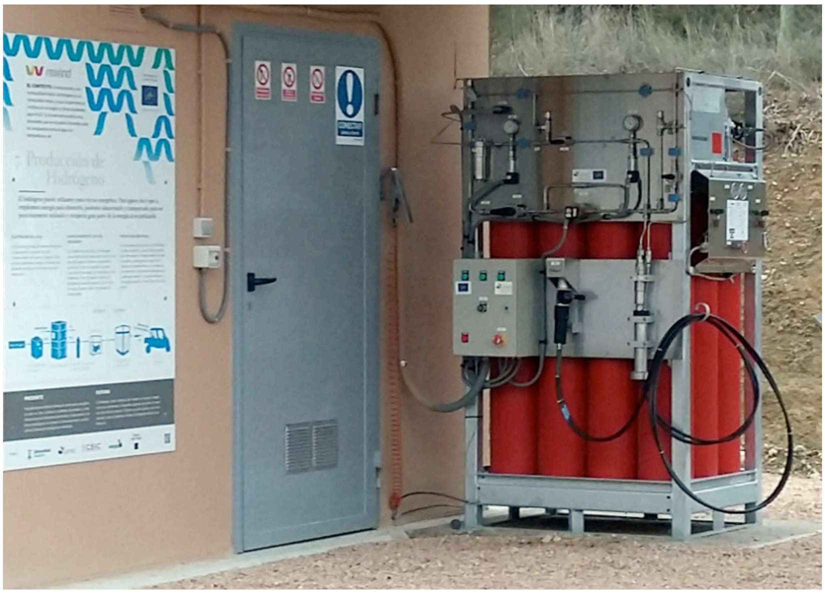

Figure 4 Hydrogen refuelling station

Figure 5 All-wheel drive fuel cell vehicle

The management of the system can be done from the location itself or through the internet, with a computer, tablet or mobile phone. There are also two high-definition IP cameras, one of them motorized, which allow the visit and inspection of the system remotely, for purposes of demonstration, control and security. In addition, the controller collects data from inverters and sensors and sends them to an external server via the internet. Since the mobile internet coverage in the location is practically zero, a point-to-point link has been installed to connect to the net of the winery itself.

The technical room is thermally insulated and air-conditioned by means of a heat pump also supplied by the system's own renewable energy. This, in addition to making visits more comfortable in summer and winter, will prolong the life of the batteries and the electronics. As an additional safety measure, when temperatures are very low, heating resistors prevent the freezing of the water destined to the production of hydrogen.

As for the loads, the motors of the pumps of greater power have been equipped with frequency inverters and the smaller ones with progressive starters. Each device has been determined how critical it is and its degree of manageability. Thus, some are automatically managed by the system and others are operated by the user, either manually or by daily or weekly programing. The controller includes hardware and software developed specifically in the project.

Table 2 Data collection to analyse socioeconomic impact

Group		
People	Inhabitants of the region	
	Visitors	
	Workers of the region	
	Consumers of the company's products	
Business	Customers	Wineries in the region
		Other companies in the region
	Suppliers	Services: hotels, restaurants, shops…
		Supplies for renewable energy systems
Institutions	Public	Municipal, provincial and regional administration
	Private	Consumer and business associations
	Scientific community	Schools, colleges and universities
		Research centres

To complete the study, the local socioeconomic impact caused by the implementation of the proposed renewable energy systems has been evaluated. Among the different methods available, the contingent valuation method, which is directly evaluated through surveys, has been chosen (UNDP – Seemin Qayum, 2012). Table 2 shows the identified interest groups, which should be consulted.

Conclusion

The LIFE REWIND project fights against climate change in the rural environment, both by mitigation and adaptation. As mitigation, it reduces CO_2 emissions related to energy consumption in agricultural activities and industries. As adaptation to climate variations, it allows the production of clean energy for irrigation in isolated or remote locations. Furthermore, noise, spills and other environmental impacts of diesel are avoided, as well as the impact on the landscape of the electricity grid in natural areas. The approach to a specific sector (the wine industry) allows for the establishment of common characteristics and to facilitate the replication of the proposed solutions.

Regarding the prototype, the energy generated during a year of operation has been of 70,545.60 kWh, which has obtained a saving of 47.9 tons of CO_2. It is probably the first time that hydrogen is produced from electricity generated on-site by a stand-alone renewable energy system, to be used for mobility on the farm itself. Although this part of the prototype is not yet economically profitable, it opens the door to the transition of the agricultural machinery leaving the diesel and becoming electric, with fuel cells or with batteries. All this has been achieved by producing the energy on-site, from renewable resources and in the farm itself.

There are several innovations introduced by the LIFE REWIND project. One of them is the support for floating photovoltaic panels in irrigation ponds. There were other floating supports, but their characteristics were not suitable for use in this kind of ponds because of its frequent filling and emptying. The floating system developed for the project can occupy practically all the surface of the pond if necessary and it adapts perfectly to the differences of level by the filling and emptying of the pond. In addition, the inclination of the panels is intended for the irrigation season. The project studies the thermal effects that can increase the performance of the panels, as well as the reduction of the water loss of the pond by evapotranspiration.

Having studied the case of vineyards in Spain and in the rest of southern Europe, the REWIND project has demonstrated the technical and economic feasibility of off-grid photovoltaic generation systems, avoiding the diesel generation sets and the extensions of the electrical grid. The project has find an optimum sizing procedure, incorporating advanced methods such as genetic algorithms. In order to facilitate replication in every specific case, two user-friendly software tools have been developed for future distribution. Another result is a positive impact on rural society and economy. In a vineyard and for off-grid systems, photovoltaic, whether on its own or in a hybrid combination with a small proportion of diesel, is the most appropriate generation technology. In these cases, the sizing and the management of the system are critical in order to avoid a very high cost or a high probability of failure in demand coverage. The resulting energy costs are lower than those of diesel generation, and often than those of the extensions of the electricity grid. This makes photovoltaic energy the most cost-effective and reliable alternative. For the wineries, which are usually grid-connected, photovoltaic self-consumption is the technically ideal solution to incorporate renewable energy. In this case, the size of the generator is not critical. In general, the need for a relatively high initial investment is a difficulty for the implementation of renewable generation systems.

In a stand-alone renewable energy system, maximum profitability can be achieved by installing the optimum combination of photovoltaic power, storage and in some cases hybrid generation. In order to find the optimal design, it is essential to carry out the characterization of the energy demand. A high degree of communication with the user is also important, from the design phase to the start-up and subsequent maintenance. Installations carried out without these guarantees are at risk of providing inadequate service to users or completely failing. When supplying energy to pumps or other electric motors, a problem that usually arises is derived from the strong starting current of the motors, which can be solved with the use of variable frequency drivers or, at least, of motor soft starter. Much more difficult to solve are electromagnetic interferences and harmonics, which require highly qualified technicians.

Acknowledgments

The authors wish to thank the LIFE Program of the European Commission for its financial support of the LIFE REWIND project (LIFE13/ENV/ES/000280).

References

Bernal-Agustín, J. L., & Dufo-López, R. (2009). Simulation and optimization of stand-alone hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, *13*(8), 2111–2118. https://doi.org/10.1016/j.rser.2009.01.010

Bhattacharyya, S. C. (2012). Review of alternative methodologies for analysing off-grid electricity supply. *Renewable and Sustainable Energy Reviews*, *16*(1), 677–694. https://doi.org/10.1016/j.rser.2011.08.033

Carroquino, J., Dufo-López, R., & Bernal-Agustín, J. L. (2015). Sizing of off-grid renewable energy systems for drip irrigation in Mediterranean crops. *Renewable Energy*, *76*, 566–574.

EEA. (2016). Technical report No 15/2016 Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016. Submission to the UNFCCC Secretariat, (15). Retrieved from http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2013

External, D. F. O. R., Of, P., & Union, T. H. E. (2014). Directorate-General for External Policies of the Union Study Human Rights Implications of the Usage of, 5, 7, 15. https://doi.org/10.2861/75161

Goel, S., & Supriya, M. (2015). Adoption of Renewable Energy Technologies by Rural Population : Impact on Quality of Life, *2*(2), 136–139.

Hao, L., Li, X., Cao, K., & Ma, H. (2016). Ningxia update: Government policy and measures for promoting a sustainable wine industry. *BIO Web of Conferences*, *7*, 3021. https://doi.org/10.1051/bioconf/20160703021

Lal, R. (2004). Carbon emission from farm operations. *Environment International*, *30*(7), 981–990. https://doi.org/10.1016/j.envint.2004.03.005

Moreda, G. P., Muñoz-García, M. A., & Barreiro, P. (2016). High voltage electrification of tractor and agricultural machinery - A review. *Energy Conversion and Management*, *115*(x), 117–131. https://doi.org/10.1016/j.enconman.2016.02.018

Mozell, M. R., & Thach, L. (2014). The impact of climate change on the global wine industry: Challenges & solutions. *Wine Economics and Policy*, *3*(2), 81–89. https://doi.org/10.1016/j.wep.2014.08.001

Sahu, A., Yadav, N., & Sudhakar, K. (2016). Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews*, *66*, 815–824. https://doi.org/10.1016/j.rser.2016.08.051

Schneider, U. A., & Smith, P. (2009). Energy intensities and greenhouse gas emission mitigation in global agriculture. *Energy Efficiency*, *2*(2), 195–206. https://doi.org/10.1007/s12053-008-9035-5

UNDP – Seemin Qayum, S. G. and Y. G. (2012). Multi-Stakeholder Decision-Making. A Guidebook for Establishing a Multi-Stakeholder Decision-Making Process to Support Green, Low-Emission and Climate-Resilient Development Strategies Empowered.

Yaqoot, M., Diwan, P., & Kandpal, T. C. (2016). Review of barriers to the dissemination of decentralized renewable energy systems. *Renewable and Sustainable Energy Reviews*, *58*, 477–490. https://doi.org/10.1016/j.rser.2015.12.224

Contact email: javier.carroquino@intergia.es