Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 142 (2017) 3008–3013

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Sustainable mini-grid

Anna Lewandowska-Bernat[a], Umberto Desideri[a]

[a]Depatment of Energy, Systems, Territory and Construction Engineering, University of Pisa, Largo Lucio Lazzarino, 56122 Pisa, Italy

Abstract

Paper summarized the research done in min-grid field. Mini-grid is small, stand-alone power system, which role is to provide constant and affordable electricity in remote places, where the connection with main grid is unprofitable. Mini-grids are important tools in fight with power-poverty in developing countries. The economics of power technologies is widely analyzed in different studies. The paper presents the advantages of application of integrated sustainable assessment for analyzing different power technologies for mini-grids. The paper highlight the importance of environmental and social aspects and its influence on local community.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: mini-grid; hybrid syste; hydrogen storage; intergarated sustainable assessment;

1. Introduction

In XXI century, there is still high percentage of people without the electrification. It is estimated that more than 1.3 billion people in the world have no access to electricity [1]. Such problem is called power poverty. The problem occurs mainly in developing countries, in remote places, where a connection with main grid is unprofitable. To provide electric energy a stand-alone systems (SAPS) also known as remote area power supply (RAPS) are constructed. Such system is an off-grid system composed of one or more generation sources, storage system, converter and set of loads.

Mini-grid should be self-sufficient and provide constant access to electricity for the local community. It is also important to consider further planning in system design step. Micro-grids can be connected to larger grids, when necessary. In such solution, they can exchange electric power with larger system. Important problem, which should be considered before grids connection is the rapid increase of intermittent power in the system, which would create the system fluctuations. To prevent such situations, it is crucial to invest in balancing technologies at the design step.

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.
10.1016/j.egypro.2017.12.437

Nomenclature

AC	alternating current
DC	direct current
LCA	life cycle assessment
NPV	net present value
RAPS	remote area power supply
ROI	return on investment
SAPS	stand-alone power system

2. Mini-grids

A task of mini-grid is to provide constant and affordable electricity for range of customers such as residential buildings, commercial entities, industrial parks and non-interconnected zones. The grids can have different electric characteristic: direct current (DC) or alternating current (AC). Recently, very popular are stand-alone hybrid renewable energy systems. They consist of two or more different energy generation sources. Mini-grids system supplied by renewable sources should be supported by proper energy storage system. Ustun et al. in [1] has summarized developments in mini-girds around the world. Most popular hybrid system has been analyzed in [2], [3].

Most popular energy storage system are batteries. Batteries provide only short term storage. They have short life cycle. For this reasons researches are looking for longer-period storage. One of such technologies is hydrogen storage [4], [5].

3. Integrated sustainable assessment

Integrated assessment is new approach for estimating a profitability of new technology. Standard approach of evaluating economic profitability is not sufficient for technology comparison. Economic indicators such as NPV (net present value) or ROI (return on investment) do not count an impact of the technology on environment or on the society. The costs of health- damaged caused by polluting technologies are neglected in the investment-making process. Integrated assessment such as life cycle assessment (LCA) or nexus consider the impact of the technology on environment. Such approach can allow to mitigate future problems and unexpected costs of environmental protection policy. The integrated assessment has numerous advantages such as:

- A true measure of resources consumption
- Increase of system resilience
- Calculation of hidden cost

World Wildlife Fund and the Center for American Progress have created the worldwide simulation of global system interaction (Food Chain Reaction project). The authors have shown the relations between economy, climate, energy, food and water systems. All systems in the world are connected in the network of dependencies. The plan of one's system management influence other network's participants in global scale. The study has shown that changes in one local sector can influence global system. For this reason, even small, local projects should be analysed not only from local perspective but also from wider perspective. This approach will be presented in next section.

Fig. 1 shows the complexity of the relations between different sectors. The figure shows how complex are the relation between different sections. The choices made in energy sector influence directly and indirectly other sectors such as water management or food sector.

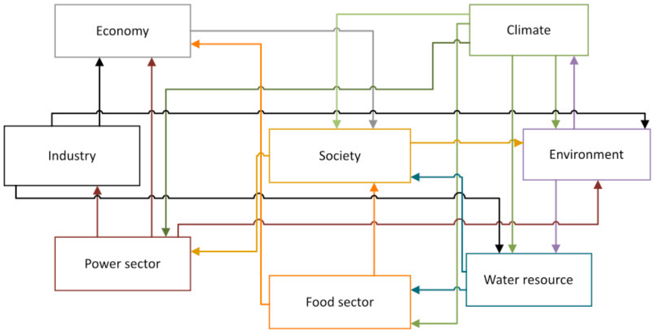

Fig. 1. Relations between different sectors

For that reasons, there is need for more complex assessments, which will count all three sustainable aspects of energy systems: economy, environment and social. Integrated sustainable assessment involves the integration of sustainability indicators via a multi-criteria decision analysis to determine the most sustainable options for the future [2]. The analysis must be done for specified scenarios and the time horizon. Fig. 2 presents the scheme of integrated sustainable assessment of energy technology.

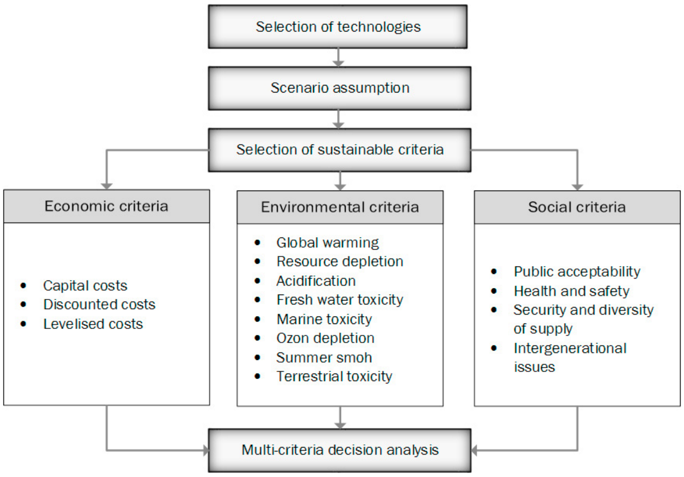

Fig. 2. Integrated sustainability assessment

Life cycle assessment is useful tool for energy system analysis [6].

4. Integrated assessment of mini-grid

Mini-grid integrated assessment should analyze the choice of power generation unit not only in economic context but also its influence on local environment and community. In this section, most important aspects of stand-alone system will be analysed. The analysis will consider two, variable sections of stand-alone system: power generation and energy storage technology. The study will be limited to renewable sources: wind and PV, diesel generator and as for the storage technology: batteries and hydrogen storage system.

4.1. Levelized cost of electricity

Levelized cost of electricity depends on the location and size of the grid. In [7] there can be found the oriented LCOE for different countries. International Energy Agency in [8] provide the levelized costs of electricity for off-grid technologies in sub-Saharan Africa, 2012.

4.2. Emissions

Each technology causes emissions. There are two emissions source in power technologies. One are emissions produced during the energy production. Other are the emissions produces during technology assembling.

Table 1. Emissions from different mini-grid technologies, based on [9]

		Solar energy	Wind energy	Diesel generator
Emissions factor for electricity generation [kg/MWh$_{out}$]	CO_2 - eq	13-190	3-41	530–900
	NO_x	0.15–0.40	0.02–0.11	0.5–1.5
	SO_2	0.12–0.29	0.02–0.09	0.85–8
		Solar electrolysis	Wind electrolysis	
Emissions factor for electricity generation [kg/kgH_2]	CO_2 - eq	0-7	0-1.5	530–900
Average AP values [gSO_{2eq}/kgH_2]	SO_2	0-27	0-2.5	

4.3. Water usage

Water is one of the most important resources in the world. Although water covers 71% of earth surface, only 3% of it is fresh water, which can be utilized in households or industry. Water in energy sector is used as a coolant or steam source. In the United States power plants use 11–22 billion litters of water every day [8]. This shows how water-consuming are power technologies. Table 2 presents the water usage of power technologies. In case of PV and wind sources water usage during plant operation can be neglected. Values presented in the table present the water usage during plant production.

Table 2. Water usage in power technologies [9], [10]

	Wind	Solar PV	Oil	Hydrogen storage
Water consumption in	<1-9 gal/MWh	10-210 gal/MWh	500-6000 litters/toe	26.7 L/kg H_2
Water withdrawal in	13-83 gal/MWh	1-1600 gal/MWh	400-4000 litters/toe	

Water used in oil production depends on an extraction technology [10].

4.4. Fuel

Renewable sources are clean-fuel and zero-emissions technologies. In case of diesel generator, fuel environmental impact is much stronger. There are three environmental impact stages of oil fuel life cycle: production, transportation and utilization.

Another aspect, which concerns imported fuel is energy security. Fuel imposts depends on world's economic situation. Although those are statistical method to predict future oil price, the reality shows that the prices fluctuate. This can affect the profitability of oil-based energy.

4.5. Land use

Land use is another important aspect, which should be taken into account during the system design. Conventional power plants occupy less space than the renewable sources. To obtain the same amount of power renewable sources will occupy more land.

5. Conclusions

Mini-grids are important solutions for energy poverty problem. The proper design of the system is crucial to maintain sustainable development. Economic analysis calculates only profitability of the technology, but it does not analyze the influence of the technology on the environment and the society. The best tool to analyze relationships between all sectors in the integrated sustainable assessment.

References

[1] T. S. Ustun, C. Ozansoy and A. Zayegh, "Recent developments in microgrids and example cases around the world—A review," *Renewable and Sustainable Energy Reviews,* no. 15, pp. 4030-4041, 2011.

[2] H. Rezk and G. M. Dousoky, "Technical and economic analysis of different configurations of stand-alone hybrid renewable power systems – A case study," *Renewable and Sustainable Energy Reviews,* vol. 62, pp. 941-953, 2016.

[3] J. L. Bernal-Agustın and R. Dufo-Lopez, "Simulation and optimization of stand-alone hybrid renewable energy systems," *Renewable and Sustainable Energy Reviews,* vol. 13, pp. 2111-2118, 2009.

[4] M. Little, M. Thomson and D. Infield, "Electrical integration of renewable energy into stand-alone power supplies incorporating hydrogen storage," *International Journal of Hydrogen Energy,* no. 32, pp. 1582-1588, 2007.

[5] K. Agbossou, M. Kolhe, J. Hamelin and T. K. Bose, "Performance of a Stand-Alone Renewable Energy System Based on Energy Storage as Hydrogen," *IEEE TRANSACTIONS ON ENERGY CONVERSION,* vol. 19, no. 3, pp. 633-640, 2004.

[6] R. Brizmohun, T. Ramjeawon and A. Azapagic, "Life cycle assessment of electricity generation in Mauritius," *Journal of Cleaner Production journal,* no. 106, pp. 565-575, 2015.

[7] Bloomberg New Energy Finance, "Levelised cost of electricity," Bloomberg L.P., 2015.

[8] K. Averyt, J. Fisher, A. Huber-Lee, A. Lewis, J. Macknick, N. Madden, J. Rogers and S. Tellinghuisen, " Freshwater use by U.S. power plants: Electricity's thirst for a precious resource. A report of the Energy and Water in a Warming World initiative," MA: Union of Concerned Scientists, Cambridge, 2011.

[9] J. Meldrum, S. Nettles-Anderson, G. Heath and J. Macknick, "Life cycle water use for electricity generation: a review and harmonization of literature estimates," *Environemtal Research Letters,* no. 8, pp. 1-18, 2013.

[10] International Energy Agency, "Water Energy Nexus. Excerpt from the World Energy Outlook 2016," IEA Pulications, Paris, 2016.

[11] E. E. Gaona, C. L. Trujillo and J. A. Guacaneme, "Rural microgrids and its potential application in Colombia," *Renewable and Sustainable Energy Reviews,* vol. 51, pp. 125-137, 2015.

[12] E. Santoyo-Castelazo and A. Azapagic, "Sustainability assessment of energy systems: integrating environmental, economic and social aspects," *Journal of Cleaner Production journal,* no. 80, pp. 119-138, 2014.